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A study of color image quality with respect to screen angle arrangement in multicolor halftone printing

Ted (Te-Chung) Chen

A STUDY OF COLOR IMAGE QUALITY WITH RESPECT TO SCREEN ANGLE ARRANGEMENT IN MULTICOLOR HALFTONE PRINTING

by

Ted (Te-Chung) Chen

B.E. Chinese Culture University
(1976)
B.S. Western Michigan University
(1979)
M.S. Rochester Institute of Technology
(1983)

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Signature of the Author ______________________

Accepted by P. Mounrili
Coordinator, M.S. Degree Program

College of Graphic Arts and Photography
Rochester Institute of Technology
Rochester, New York

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Dr. Edward Granger, Thesis Advisor

Professor Joseph Noga

Professor Bob Chung

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Date

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Submitted to the
Center for Image Science
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ABSTRACT

The advantage of using a single screen-angle (Dot-on-Dot) reproduction for multicolor halftone printing is a sharper reproduction with the decrease of a rosette pattern in all image areas.

The purpose of this study was to quantify the differences of color image quality between conventional reproduction using four screen-angles and a single screen-angle printing technique. In addition, the influence of screen frequency to the final color image quality in the Dot-on-Dot printing was also investigated.

The results of this study confirmed that there is a linearity of image quality for all color halftone printing regardless of the arrangement of the screen angle. Test results also indicated that Dot-on-Dot was preferable to the conventional four screen-angle technique at the low screen frequency. Under different reproduction circumstances, input image quality and reproduction screen frequency have different weight toward determining the quality of the final reproduction.

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I would like to express my deepest appreciation to my thesis advisor, Dr. Edward Granger of the Eastman Kodak Company, for his kindness, patience and guidence throught the period of this thesis. Without access to his extensive repertoire of knowledge, this thesis would never have been possible. My thanks also to all the judges who participated in the subjective analysis.

Last, but not least, I wish to thank and dedicate this thesis to my parents and my brother in appreciation of their support, encouragement and confidence in me.

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I. INTRODUCTION

A. Objectives of the study

Conventional multicolor halftone printing requires four printing plates for each of the subtractive primary colors and black. Each of the plates is produced from a halftone negative (or positive) which has a specific screen angle. Four angles are used to compose a process color halftone image. Typical angles are 45 degree for the Magenta color, 75 degree for the Cyan color, 90 degree for the Yellow color, and 105 degree for the Black color. When the four halftone images, each with its own unique screen angle, are superimposed together, a visiable interference pattern known as the "Rosette" pattern appears. Whenever two periodic structures which differ in frequency or angle, or both, are superimposed[1], a moiré pattern is obtained. A Rosette pattern is a kind of moiré pattern. In general, a Rosette pattern is not objectiable to the eye. Therefore, it is acceptable for most four color printing. However, the appearance of an interference pattern in the image areas deteriorates the percetive quality of the image to a certain extend. It is considered a drawback in multiangle halftone printing.

In single screen-angle multicolor halftone printing (it is also often called Dot-on-Dot printing), four halftone negatives are made with the same screen angle. When all screen angles are precisely aligned and each process color is exactly registered, the halftone dots of the subsequent color should be printed exactly on the same site which is already occupied by previous color dots. Therefore, the overlapping pattern is homogeneous.

James Rich, in 1982, at the annual TAGA meeting presented the paper "A Comparison of Four Color Printing At One Angle and at Four Angles"[2], determined that the coarse line screen rulings at a single screen-angle exhibited more apparent sharpness than at four angles. And at a single screen-angle, the interference pattern (the rosette pattern) was eliminated[3]. For many years, people have been aware of the improvement of image quality that can be achieved by selecting a higher screen frequency (within a limited range) in halftone printing.[4] The finer the screen ruling, the greater the potential for holding detail in the reproduction[5]. But the interference pattern has always existed at all screen frequencies. Dot-on-Dot printing eliminates the interference pattern which makes the image appear sharper without using higher screen rulings. This attraction makes Dot-on-Dot printing more desirable by the newspaper industry which uses the coarse screen rulings and uncoated paper (newsprint stock) as their standard condition for reproduction. Test of the Chemco Company's " Easy Color System "[6] indicates that Dot-on-Dot printing on newsprint produces superior color, gives the impression of a finer line screen, eliminates the rosette and moire patterns, and produces consistant flesh tone.

As a general understanding, the object of any printing process is to produce an image which will be viewed in some way, thus the quality of the reproduced image is being assessed by subjective visual judgement. In other words, "Quality is not a property of images, but a description of a judge's reception to images."[7] Although several physical variables such as relative contrast, sharpness and evenness of solids and halftones have been determined to be some of the fundamental elements that contributed to the visual subjective quality of an image.[8] However, the measurement of such variables must always be related to the visual experiences.[9] Therefor, in this study, the term "Image Quality" will be refered to as the satisfaction of the overall percetive appearance of an image.

B. Hypothesis

The improvement of color image quality by using Dot-on-Dot printing has been noticed. But no mention was made in these studies of the quantitative amount of improvement, nor the significance of screen frequency to the color image quality in this technique. Instead, only a qualitative evaluation has been made. Therefore, the objective of this study is to quantify the differences between the conventional four screen-angle printing method and the single screen-angle printing method with respect to the color image quality. In addition, the influence of screen frequency to the final color image quality in the Dot-on-Dot reproduction will also be investigated.

The results of these evaluations will be gathered and analyzed, and the status of the following hypotheses will be determined.

Hypothesis 1: The quality of the halftone color image produced using the conventional four screen-angle method does not increase as the screen frequency increases.

Hypothesis 2: The quality of the halftone color image produced using the conventional four screen-angle method does not have a linear relationship to the input image quality for all screen frequencies.

Hypothesis 3: The quality of the halftone color image produced using the Dot-on-Dot printing method does not increase as the screen frequency is increased.

Hypothesis 4: The quality of the halftone color image produced using the Dot-on-Dot printing method does not have a linear relationship to the input image quality for all screen frequencies.

II. LITERATURE REVIEW

A. Related Study:

Previous image quality studies that have related subjective measures of screened image quality did not deal with the phenomena of an interference pattern. Chantana Tangseree[10] at RIT did a study of the relationship between screened image quality and screen frequency, and only monochromatic single screen-angled images were investigated. The result of Tangseree's investigation confirmed that screened image quality is a linear function of the input image quality of different screen frequency for a monochromatic image. She also determined that for a given reproduction system, there was a breaking point in the relationship of image quality and screen frequency. Beyond that point, the improvement of screened image quality was not proportional to the increase of screen frequency with respect to the human visual perception. Tangseree's study prompted the basis of comparison for this thesis.

In a facsimile reproduction system, the image quality after processing will be linearly related to the image quality of the original.[11] Therefore, a straight line can relate the image quality of the original, and the reproduction can be used as a reference to indicate the quality of the reproduced image.(Figure 1)[12].

When photographic originals have been produced in different quality levels but with equal quality steps, we can expect to see the relationship of the screened image with different screen frequencies as straight lines parallel to the original quality line separated by certain distances.(Figure 2)[13].

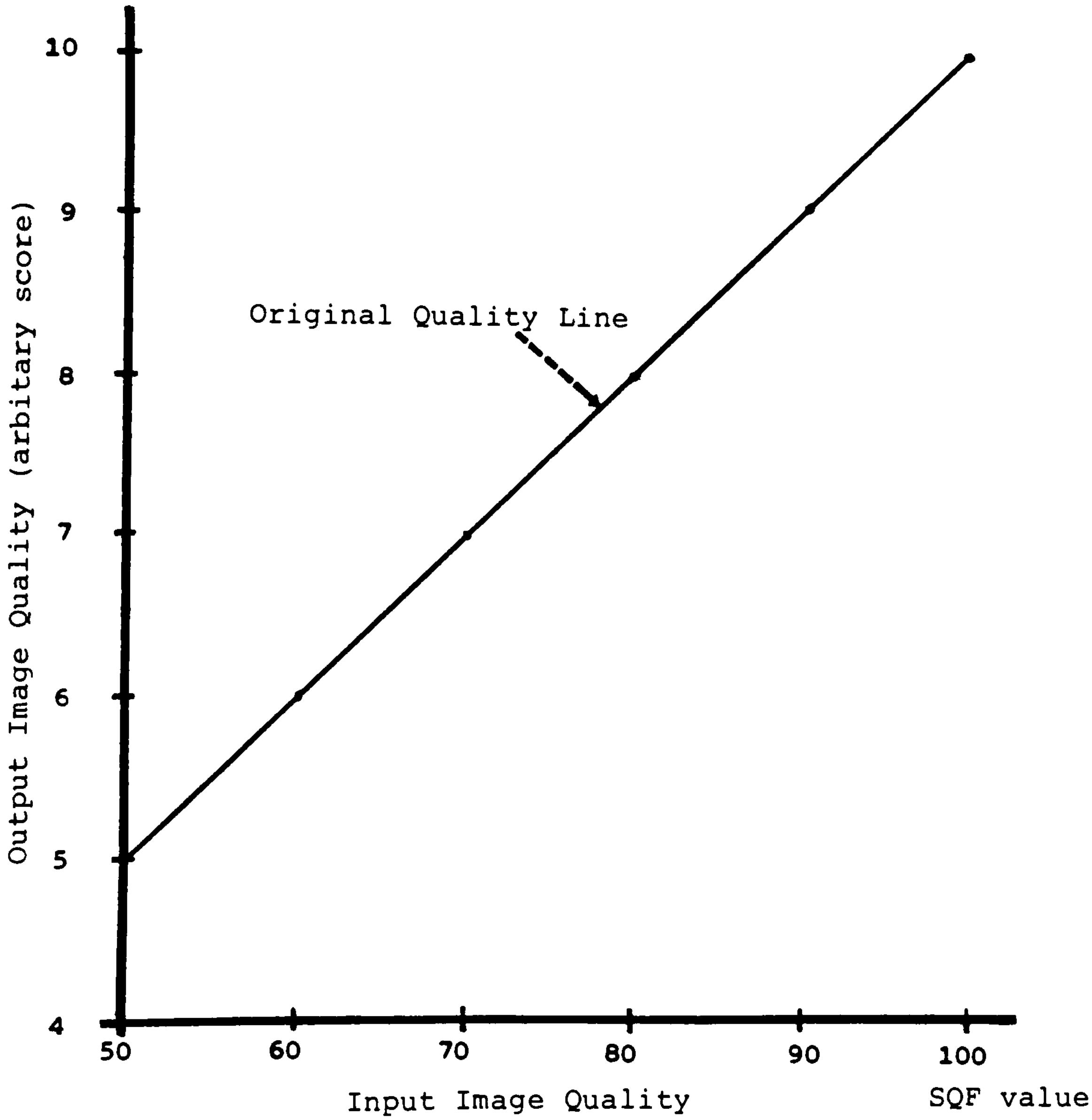


Figure 1: Model of Image Quality Scaling Method

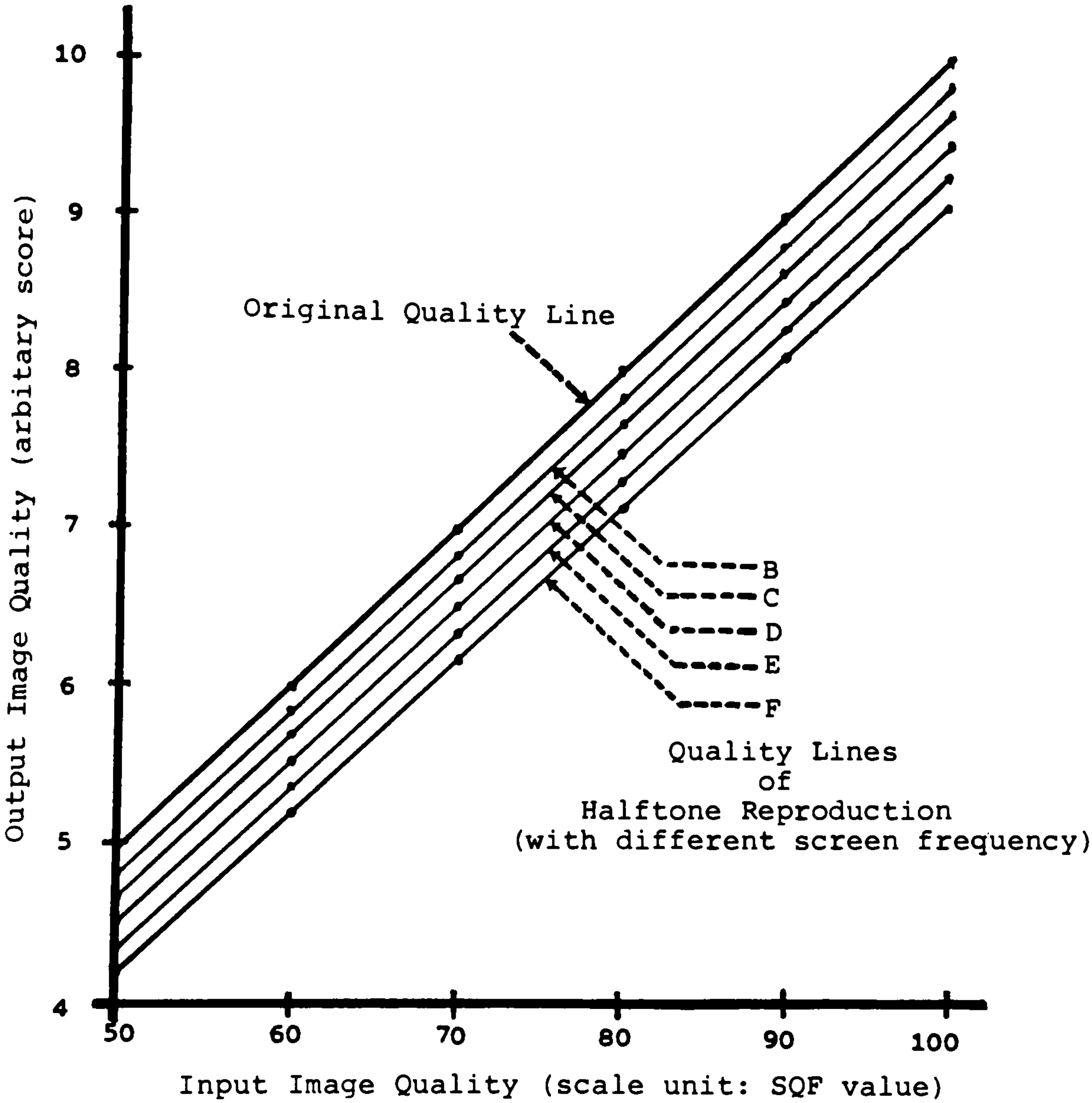


Figure 2: Model of Image Quality Scaling for Halftone Reproduction

In the actual reproduction system, due to the existance of variations in each step, such as substrate surface conditions, maximum ink density, and press condition which will deteriorate the reproduced image quality. The straight lines in Figure 2 will not be evenly spaced. At a certain point, the space between two consecutive lines will be larger than others. This gap will shift from one screen frequency to another when new variables are introduced into the existing reproduction system.

To determine the breaking point in each of the techniques, the subjective quality factor (SQF) was used. From this the quantified difference can be derived.

B. The Subjective Quality Factor (S.Q.F.)

Print quality is a characteristic that, although it depends on on a series of objective quantitives, implicates a psychological evaluation by the observer. As for all the qùantities that are evaluated by means of a psychological procedure, it is very difficult to measure it objectively. For this reason, a practical image quality criterion, the Subjective Quality Factor (SQF)[14] has been used to define the overall quality of an imaging system. This factor suggests that the region of frequencies to which the human eye is most sensitive is used as a bandwidth over which the area under the system MTF is evaluated. The spatial frequency region (or bandwidth) used to determine the SQF value is specified to be between ten and forty cycles/mm, as measured at the retina.[15] These values cover the region of most significant visual response. SQF was so defined as to duplicate the operation of the human visual system as shown in figure 3. This factor correlates with the subjective response and, in one dimension, is defined as:

$$SQF = K\int_{f_{c/2}}^{2f_c} T(f)d(\text{Log } f)$$

where fc = center of a defined visual passband.

T(f)= optical transfer function.

f = spatial frequency.

K = normalization constant, chosen so that SQF=100 where T(f)=1.

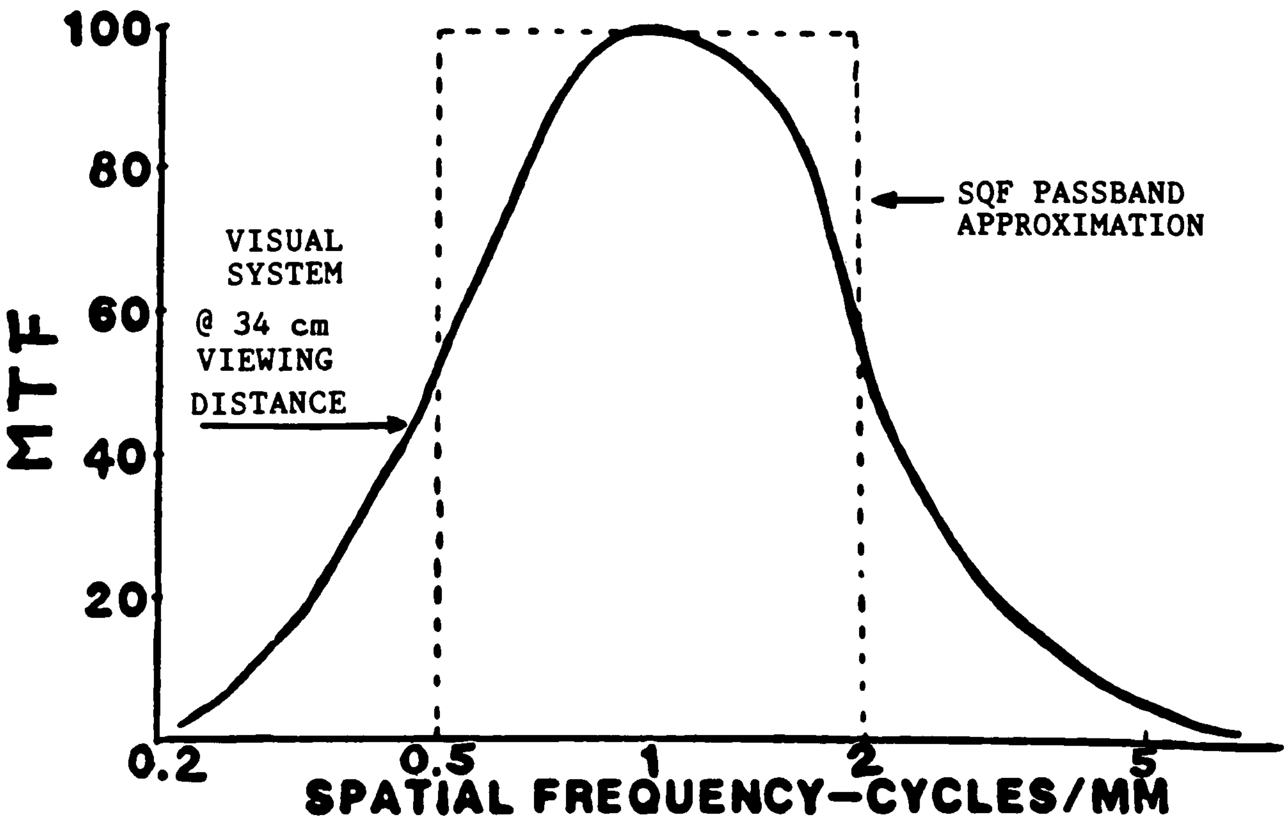


Figure 3: VISUAL SYSTEM RESPONSE

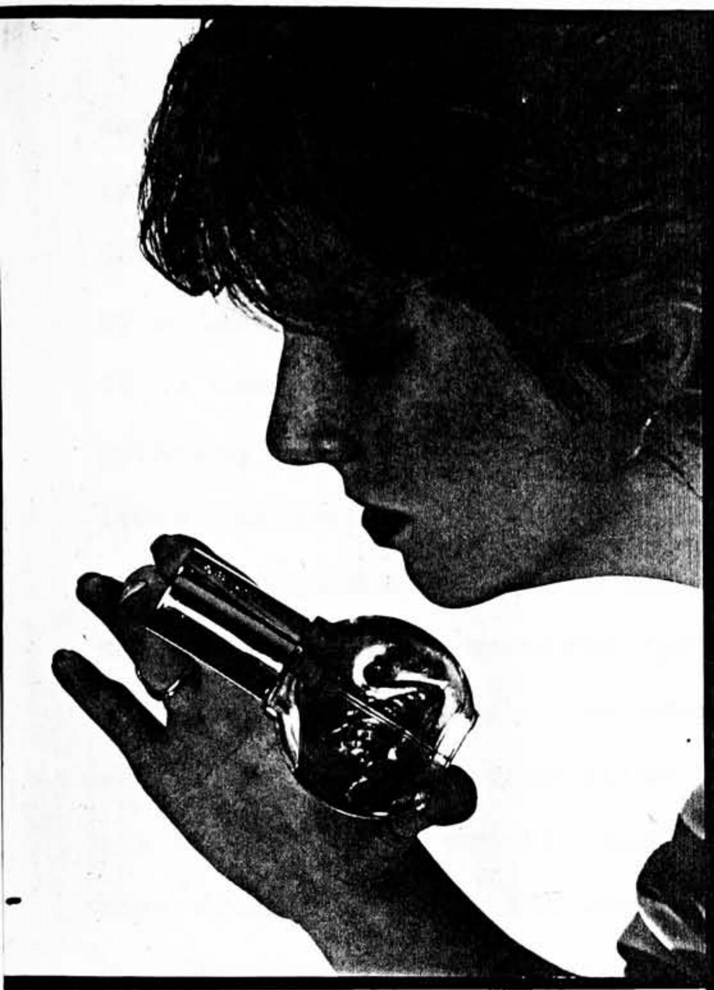
To develop the required subjective scaling of the reproduced color images, the method of pair comparisons[16] was used. This method used preference rations to scale the stimuli. From the results of pair comparison judgment, estimates of the preference rations and subjective distances can be computed for each pair. The advantages of this method are that the responses are easy to make and requires no training of the judges.

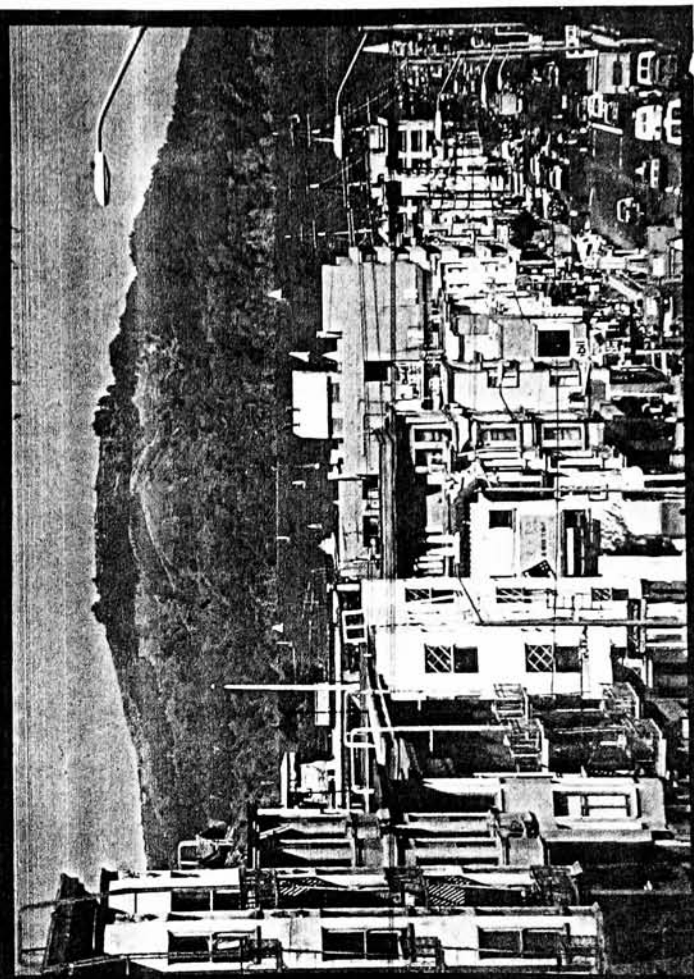
III. METHODOLOGY

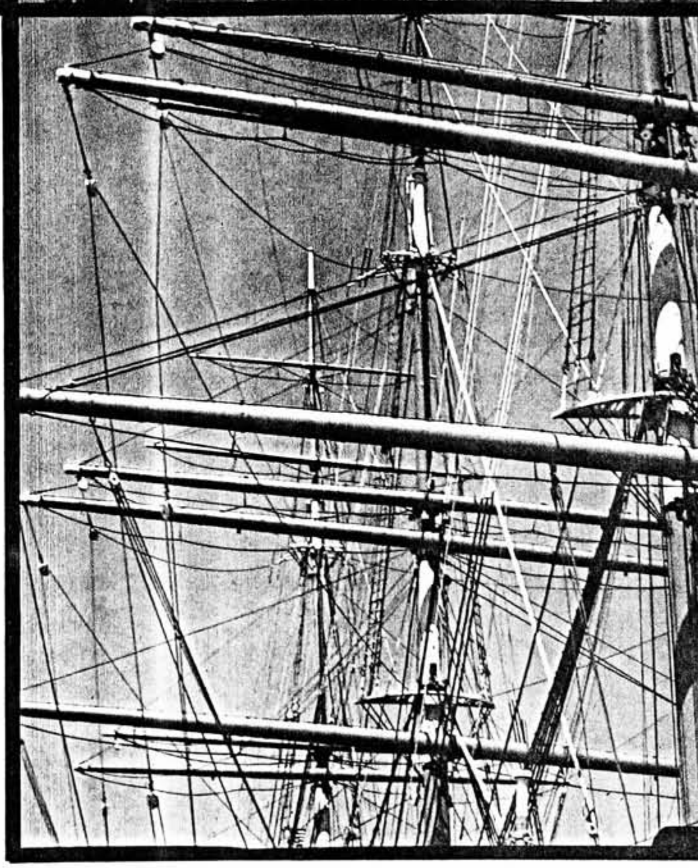
A. Preparation of the Test Images:

Three photographic transparencies were chosen. The scenes represented the range of subjects found in general photography. They included a busy background scene, a simple subject scene, and a subject with lots of detail (Figure 4). After the transparencies had been chosen, they were assembled together to make one flat. This flat served as the original in this study. All the images in the original flat are in sharp focus. They represent the best quality available for duplication. In the production of the duplicates, known degradation in image quality were induced by carefully controlled defocusing of the copy lens. Five different quality levels were used in the five duplicate transparencies. Including the original, there were six quality levels. Between every adjacent level, the difference was made in an equal step of 10 SQF values. The quality of the best image in this study was defined as having a SQF value of 100, while the ones with lower quality were defined as 90, 80, 70, 60, and 50 respectively. For a complete discussion of the calculations involved in selecting the defocus positions, please refer to Appendix A.

Once all the test samples were ready, the six transparencies were stripped into one large flat. It was prepared for color







Scences used in this study.

Figure 4

separation on the HELL DC-399ER electronic color scanner. This is an electronic dot generating scanner in which the halftone dots are generated by the computer and exposed to the film by a laser directly without the need for a halftone screen. It is one of the most popular color scanners used in the printing industry today. Three screen frequencies 65, 85, and 120 lines per inch were used to make the halftone prints. These screen frequencies covered the range of those which are used in the newspaper and commercial printing industry.

Six quality levels for each of the three screen frequencies and two different reproduction techniques yielded a total of thirty six sets of color proofs. Each separation set contains four half-tone film positives that were used to make one process color image. An off-press proofing method- DuPont CROMALIN system was used to produce the color images. The reason for using an off-press proof is that it offers an easier way to produce a small quantity of the color prints. Furthermore, there are too many variables associated with a press run, such as dot gain, maximum ink density, ink trapping, etc.. These variables would make it difficult to identify the real reasons for differences in image quality in the two reproduction techniques being tested. The use of off-press proofing virtually eliminates these unwanted variables.

The steps of making CROMALIN proofs are laminating, exposing, and toning were repeated for each color. An additional film was laminated and exposed overall to protected the proof from damage due to handling. The exposure was done by contact printing at seventeen units of exposure time with the KOKOMO filter covered the UV light source for all four colors. The post-exposure time was fifty units without the filter. The CROMALIN Offset COM Guide (POS) was used to control the corrected exposure. Toning was done on the Automatic Toning Machine. The machine toning speed for the Yellow toner was 12 inch/minutes, the Magenta toner was for 48 inch/minutes, the Cyan toner was for 119 inch/minutes, and for Black toner it was 55 inch/minutes. The density of each color was checked right after toning to confirm the SWOP standard. The density of each color was 0.93 for Yellow, 1.41 for Magenta, 1.33 for Cyan, and 1.54 for BLack. The density latitude for all four colors were plus and minus 0.07. Relative humidity of the process room was maintained at 51%.

Once all color image samples were ready, an identification letter was randomly assigned to each sample. For the actual grading experiment, test were conducted under standard viewing conditions. A viewing booth with the 5000 degree Kelvin standard light source was used and the viewing distance was held to about thirty four centimeters.

B. Subjective Analysis:

The measurement of image quality of different reproduction techniques was performed by using the method of paired comparison.

In this method, a panel of judges were given a set of proofs that used a specific screen frequency. Within each set, images were arranged into three groups: Dot-on-Dot, conventional, and a mixture of these two techniques. Each group contains six images which represent different quality levels. Two images were shown to the judge each time. The judge were asked to ignor any scratches, dirty spots and slight color variation on some of the test images, which were added onto the test images due to processing. The judges compared one image to the other and simply demonstrated a preference. After the prefered image was chosen, a score was assigned to indicate the differences between the two images, according to the observers own judgement.

All possible combinations were shown to the judges within each group. That resulted in fifteen possible combinations. This was repeated for the other group. In all, three sets were shown, each set had three groups, each group had fifteen different combinations, making it a total of one hundred and thirty five combinations.

Fifteen judges were invited for subjective analysis. The judges were both experienced and non-experienced in the field of graphic science. They simply selected one image over the other base upon their own personal preference. In general, the evaluation process took about forty five minutes for a judge to review all one hundred and thirty five combinations. The evaluation worksheets that were used by each judge are attached in Appendix C.

IV. DATA MANIPULATION

A. Sample Arrangement:

The thirty six color halftone images were arranged into three sets of images according to their screen frequency. Within each set, images were subdivided into three groups. One group consisted of the images which were reproduced using the conventional four angle technique, another group contained the images which were reproduced by dot-on-dot technique, and the third group was a mixture of these images which were reproducted by the two techniques. The images were selected for the third group were produced at the SQF values of 100, 85 and 50. The purpose of having the third group was to determine the relationship between the two techniques at the given screen frequency.

The above arrangement was used to handle images having the same screen frequency within each image set. From one screen frequency to another, the determination of their relationship was done in an similiar manner. This was done to form a special inter-relationship group which consisted of images from all three screen frequencies. The only difference was the number of images which were selected from each reproduction technique. Instead of having three images from one reproduction technique, two images were selected. Three different screen frequencies and two images from each screen frequency were used. A total of six images were in this special group which was the same number of images as the other groups had. All images in the special interrelationship group were reproduced by the conventional technique. It was believed that people were more familiar with the images which were reproduced by the conventional technique. Thus, the relationship of different screen frequency will be determined easier by using them. Images in this special interrelationship group were reproduced from the originals which had SQF values of 90 and 60.

B. Data Collection and Manipulation:

The method of scale judgment was used to determine the relative distances among images. This method was based on the judge's magnitude estimation. By applying paired comparison, judge's observing a difference between two images can be converted into a score which indicates the degree of separation between the two images.[17] It should be pointed out that for all subjective comparison tests, there are no absolute values for the measurement. All measurements must be transformed into a reference scale, then the relative comparison can be made from this reference scale.

The technique used to score the images for each group were analyzed in the identical manner. The flow-chart of the data manipulation processing is attached for reference (Figure 5). Images in a group shown to the judges were arbitrarily

DATA MANIPULATION PROCESSING

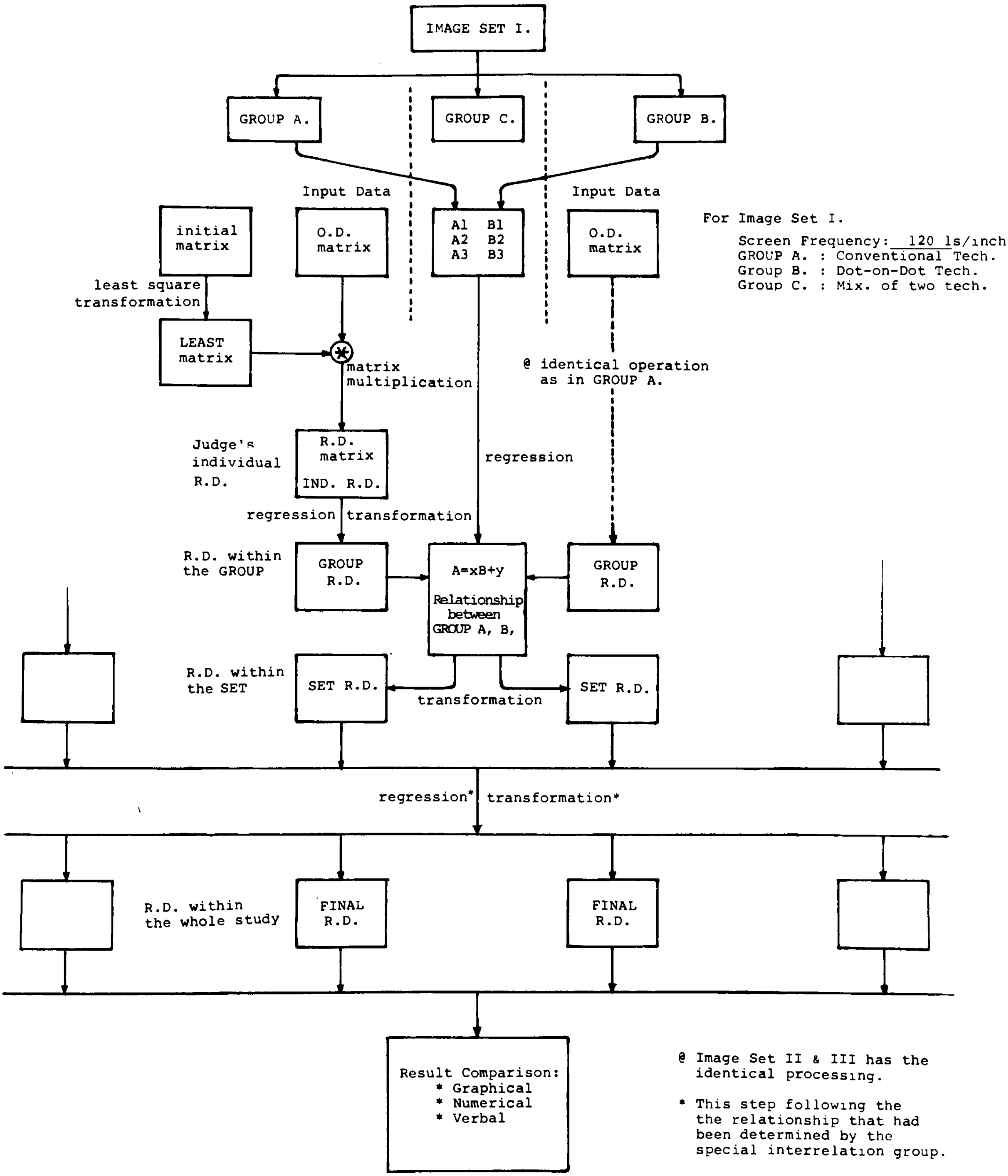


Figure 5: Data manipulation processing

assigned as A, B, C, D, E and F. The objective was to find a relative distance between images on a common scale. The relative distances of the six images in the same group were found by taking one image as the starting point and determining the distances of the others from this image. A least squares transformation was used to manipulate the data.

The zero point was randomly set for one of the six images and the distances of the other five were measured from the zero point image. For purpose of explanation, assume image A was selected as the zero point. The distance from A to B was represented as A-B. Since A was set to 0, so A-B can be substituted by -B or -1(B). For the initial matrix (M). Because A was set to zero, thus A did not occupy a space inside the matrix. Since the first row represented the distance from B to A which is (A-B or -B), thus the B column (the first column in the matrix) was set to -1. In this case, since only the distance from B to A was being determined, the remaining columns were set to zero. Similarity, the second row represented the distance between A-C, the third row represented A-D..... and so on. There were fifteen combinations within each group and hence the matrix had fifteen rows. Each row represented one combination. The least squares solution to the initial matrix was another matrix LEAST.

$$\text{LEAST} = (M^T * M)^{-1} * M^T$$

Where M was the initial matrix, and M^T was the reciprocal of M. The initial matrix was a 15*5 matrix, thus the LEAST became a

5*15 matrix. The value of the initial matrix M and the LEAST matrix is shown in Figure 6.

The judge's observation of distance between two images is refered to as observed distance--O.D.. All the O.D. values within a group were used to form the O.D. matrix, it was a 15*1 matrix. This matrix was determined as follows.

According to the judge's own preference, when two images were shown to the judge, the one with better image quality was picked up. Later, a score was given by the judge to indicate the difference of image quality between the two images. A plus (+) or minus (-) sign was used to indicated the direction of preference. For instance, image D verses E were shown to a judge. The judge prefered D over E on a score of 6. The +6 was used to represented this case. On the opposite situation, E was considered better than D with a score of 6. Then -6 was used to represented this situation. After all fifteen combinations were shown to a judge, fifteen scores were obtained to construct the O.D. matrix.

The relative distance between two images which need to be determined was refered as R.D.. The R.D. matrix was the result of the O.D. matrix multiplied by the LEAST matrix.

$$M*(R.D.)=(O.D.)$$

$$M^T*[M*(R.D.)]=M^T*(O.D.)$$

$$(M^T*M)*M^T*[M*(R.D.)]=M^T*(O.D.)$$

$$@\ M^T*M=1$$

$$[M*(R.D.)]=M^T*(O.D.)/(M^T*M)*M^T$$

$$
\text{initial matrix (M)} =
\begin{array}{cl}
\begin{array}{ccccc} & & \text{Column} & & \\ B & C & D & E & F \end{array} & \begin{array}{l} \text{Distance between} \\ \text{these two points} \end{array} \\
\begin{bmatrix}
-1 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & -1 \\
+1 & -1 & 0 & 0 & 0 \\
+1 & 0 & -1 & 0 & 0 \\
+1 & 0 & 0 & -1 & 0 \\
+1 & 0 & 0 & 0 & -1 \\
0 & +1 & -1 & 0 & 0 \\
0 & +1 & 0 & -1 & 0 \\
0 & +1 & 0 & 0 & -1 \\
0 & 0 & +1 & -1 & 0 \\
0 & 0 & +1 & 0 & -1 \\
0 & 0 & 0 & +1 & -1
\end{bmatrix} &
\begin{array}{l}
\text{(A-B) or -B} \\
\text{(A-C) or -C} \\
\text{(A-D) or -D} \\
\text{(A-E) or -E} \\
\text{(A-F) or -F} \\
\text{(B-C) or +B-C} \\
\text{(B-D) or +B-D} \\
\text{(B-E) or +B-E} \\
\text{(B-F) or +B-F} \\
\text{(C-D) or +C-D} \\
\text{(C-E) or +C-E} \\
\text{(C-F) or +C-F} \\
\text{(D-E) or +D-E} \\
\text{(D-F) or +D-F} \\
\text{(E-F) or +E-F}
\end{array}
\end{array}
$$

$$
\text{LEAST matrix} =
\begin{bmatrix}
-1/3 & -1/6 & -1/6 & -1/6 & -1/6 & +1/6 & +1/6 & +1/6 & +1/6 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1/6 & -1/3 & -1/6 & -1/6 & -1/6 & -1/6 & 0 & 0 & 0 & +1/6 & +1/6 & +1/6 & 0 & 0 & 0 \\
-1/6 & -1/6 & -1/3 & -1/6 & -1/6 & 0 & -1/6 & 0 & 0 & -1/6 & 0 & 0 & +1/6 & +1/6 & 0 \\
-1/6 & -1/6 & -1/6 & -1/3 & -1/6 & 0 & 0 & -1/6 & 0 & 0 & -1/6 & 0 & -1/6 & 0 & +1/6 \\
-1/6 & -1/6 & -1/6 & -1/6 & -1/3 & 0 & 0 & 0 & -1/6 & 0 & 0 & -1/6 & 0 & -1/6 & -1/6
\end{bmatrix}
$$

Figure 6: initial matrix and LEAST matrix

$$(R.D.)=(O.D.)/M*(M^T*M)$$

$$=[(M^T*M)^{-1}*M^T]*(O.D.)$$

since $LEAST=(M^T*M)^{-1}*M^T$, thus

$$(R.D.)=LEAST*(O.D.)$$

or [LEAST]*[Observed Distance]=[Relative Distance]

$$\begin{bmatrix} a11 & a21 & a31 & a41 & \text{------} & a151 \\ a12 & a22 & \text{----------------} & & & a152 \\ a13 & \text{--------------------} & & & & a153 \\ a14 & \text{--------------------} & & & & a154 \\ a15 & \text{--------------------} & & & & a155 \end{bmatrix} * \begin{bmatrix} b11 \\ b12 \\ b13 \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \\ b114 \\ b115 \end{bmatrix} = \begin{bmatrix} c11 \\ c12 \\ c13 \\ c14 \\ c15 \end{bmatrix}$$

Image A was set to the zero position at the start. By placing the value zero to the corresponding position (first position) in the R.D. matrix, the 6*1 matrix was the complete representation of the relative distances (R.D.) for this group of images which was determined by a given judge. This matrix was refered to as the judge's individual R.D. matrix. In order to compare the relative distances between each group and each image set, the judge's individual relative distance data was transformed into a common reference scale which was shared with the other groups and other image sets. In the data manipulation process flow-chart, the GROUP R.D. were the data sets which shared the same reference scale within a group. The SET R.D. were the data sets which shared the same reference scale within each image set. The FINAL R.D. were the data sets which had the same reference as all other image sets. The FINAL R.D. had the values that all comparison were made from them. The corresponding observation and final relative distances of each group are tabulated in Table 1.

SQF	120C	120D	85C	85D	65C	65D
50	-2.26	-2.44	-1.25	-1.04	-3.13	-0.68
60	-1.28	-1.47	-0.94	-0.77	-2.36	-0.47
70	0.31	-0.02	-1.02	-0.63	-1.70	0.64
80	2.28	1.38	-0.58	-0.11	-1.15	0.38
90	2.48	1.64	0.13	0.01	-0.71	1.27
100	3.46	2.15	0.34	0.21	0.17	1.91

Table 1: The "ORIGINAL" result data file.
@: without solid ink density factor correction

C. Data Correction by Solid Ink Density factor

According to the results of Chantana Tangseree's study, the solid ink density is an important factor in predicting reproduction image quality. It is even more important than the screen frequency factor.[18] The work of quantifing the relationship between the solid ink density and reproduced image quality was done by Wu's study.[19] He had found that the image quality scale appears linear in terms of different solid ink densities, and the difference of image quality became smaller as the solid ink density went higher (Figure 7).[20] Since the maximum ink density in the shadow area of a process color image is the result of overlapping four color inks which has the similiar appearance as the solid ink density in the black and white halftone image. It is felt that the maximum ink density factor should be put into consideration on correcting the data of this study. Wu's result provides a good means to calculate the correction factor at

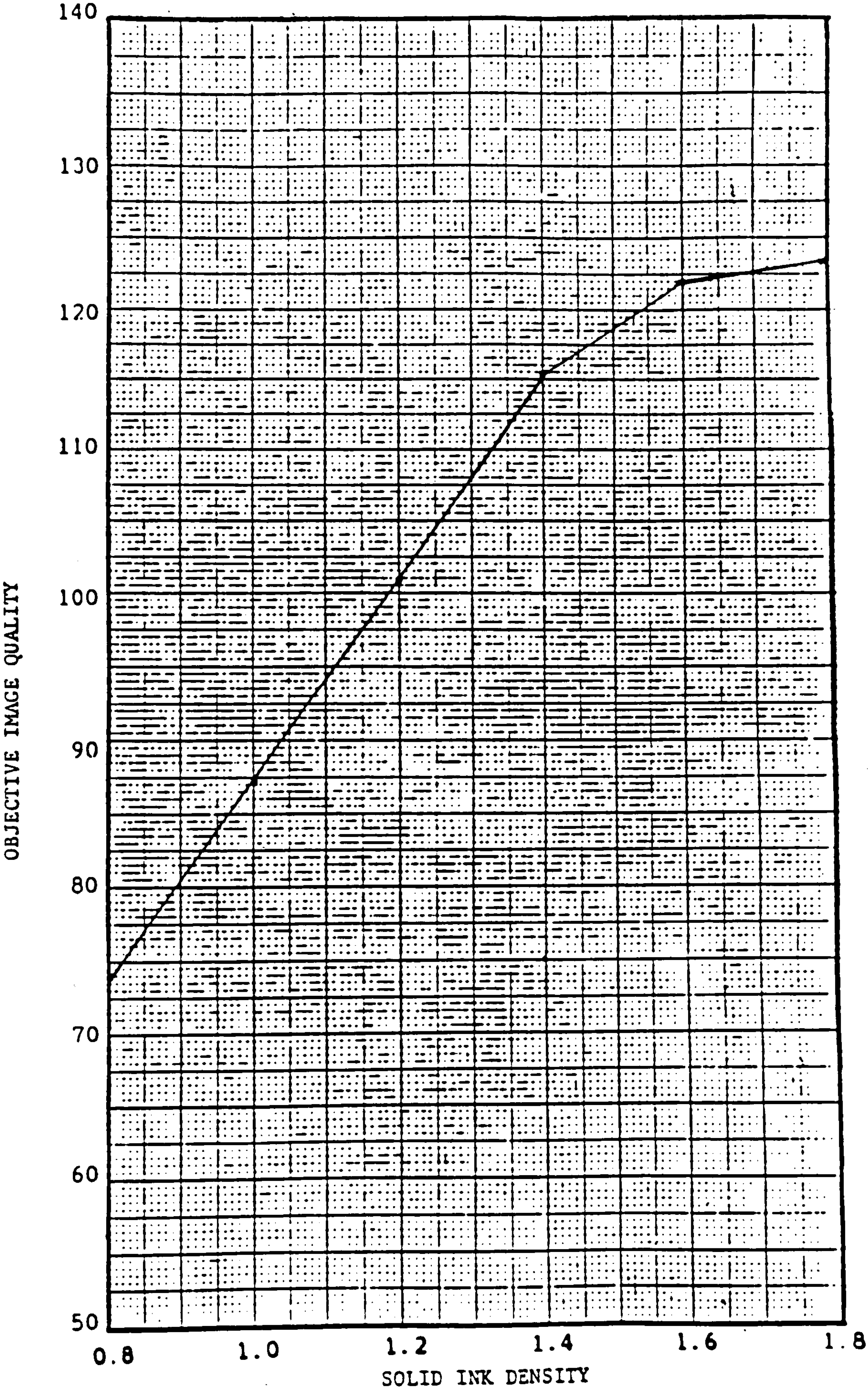


Figure 7 The relationship between image quality and solid ink density

different maximum ink densities. The maximum ink density of each color proof is given in Table 2. The resulting data after addition of the correction factor is shown in Table 3. The calculation procedure is detailed in Appendix B.

	Dmax VALUES OF EVERY PROOF PRINT					
SQF	120C	120D	85C	85D	65C	65D
50	1.53	1.54	1.55	1.52	1.47	1.66
60	1.51	1.55	1.56	1.53	1.46	1.64
70	1.52	1.64	1.53	1.49	1.52	1.68
80	1.53	1.62	1.52	1.51	1.46	1.37
90	1.55	1.64	1.55	1.41	1.51	1.41
100	1.61	1.70	1.53	1.39	1.53	1.44

Table 2: Maximum Ink Density of every color print

SQF	120C	120D	85C	85D	65C	65D
50	-2.08	-2.28	-1.11	-0.84	-2.80	-0.68
60	-1.04	-1.33	-0.82	-0.59	-1.97	-0.47
70	0.51	-0.02	-0.84	-0.35	-1.50	0.64
80	2.46	1.38	-0.38	0.13	-0.76	1.11
90	2.62	1.64	0.27	0.54	-0.47	1.80
100	3.46	2.15	0.52	0.82	0.35	2.36

Table 3: The "CORRECTED" data file.
@: Solid Ink Density correction factor=0.082

V. RESULTS AND DISCUSSION

A. Experimental Results

Image quality lines for every situation were constructed from the resulting data. These curves offer a visual means for comparing the differences of reproduced images among various reproduction conditions. Data before the correction by the solid ink density factor and after the correction were used to make separate plots. The result of the entire study is concluded in Figure 8. The image quality lines are showing an approximate linear relationship between the input (objective) and output (subjective) image quality. As the input quality increases, the output image quality also increases. Even though some of the data does not fall on a straight line, the overall pattern of the relationship is reasonable well linear. The linear correction coefficient (r value) of each individual case, before and after solid ink factor correction are shown in Table 4. From these r values, it is justified to decide that straight lines are a suitable description of the underlying relationship.

	120CON	120DOD	85CON	85DOD	65CON	65DOD
W/O SID	0.98	0.97	0.95	0.98	0.99	0.96
W/ SID	0.98	0.98	0.96	0.99	0.99	0.99

Table 4: Linear Correlation Coefficient (r value)

From other studies, we know the maximum ink density plays a very important role in the human's percetive impression of an image. By comparing the image quality line and it's value of a given reproduction situation, the importance of this factor is shown. Curves are shown in Figure 12 to 17 for screen frequencies of 65, 85, and 120 lines/inch respectively. After the solid ink density correction, the data followed the linear relationship closer. This improvement is also shown on the r values (Table 4). After the correction, four of the six values have been improvemed, the remaining two are unchanged. From these improvements, it is confident to believe that without the addition of the solid ink density factor, the data is not accurate to show the true relationship between input image quality and output image quality.

B. Result Discussion

The data in Figure 8, seems to indicate that the image quality is accending in a linear pattern in all six cases. However, the slope of the image quality lines have differences. The slope values reproted in Table 5 are determined by the linear regression lines of each case.

Repro. Tech.	120CON	120DOD	85CON	85DOD	65CON	65DOD
Slope (M value)	0.12	0.09	0.03	0.03	0.06	0.06

Table 5: Slope of Image Quality Lines

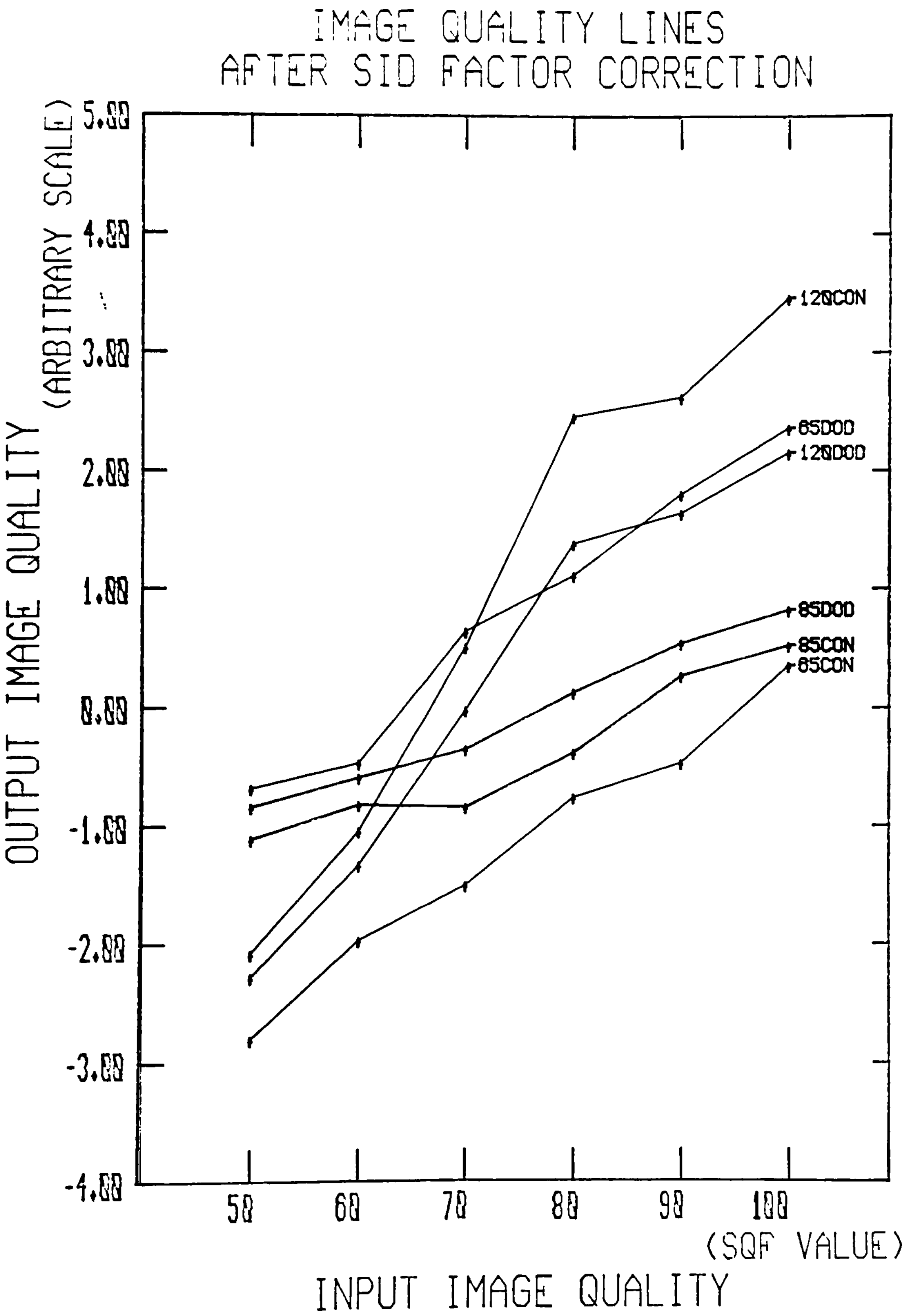


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
120CON
85DOD
120DOD
85DOD
85CON
85CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 8

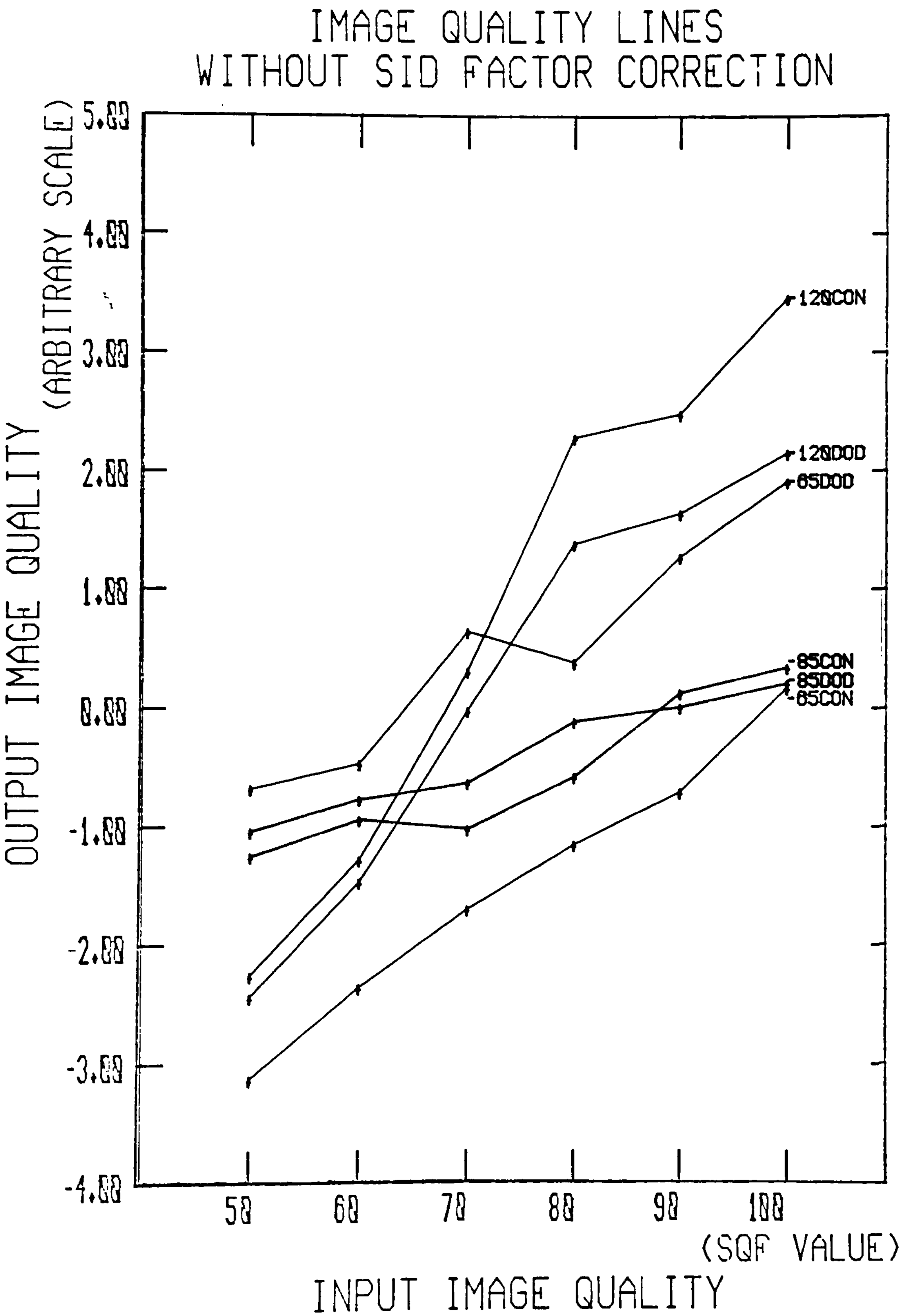


IMAGE QUALITY LINES
WITHOUT SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
120CON
120DOD
65DOD
85CON
85DOD
65CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 9

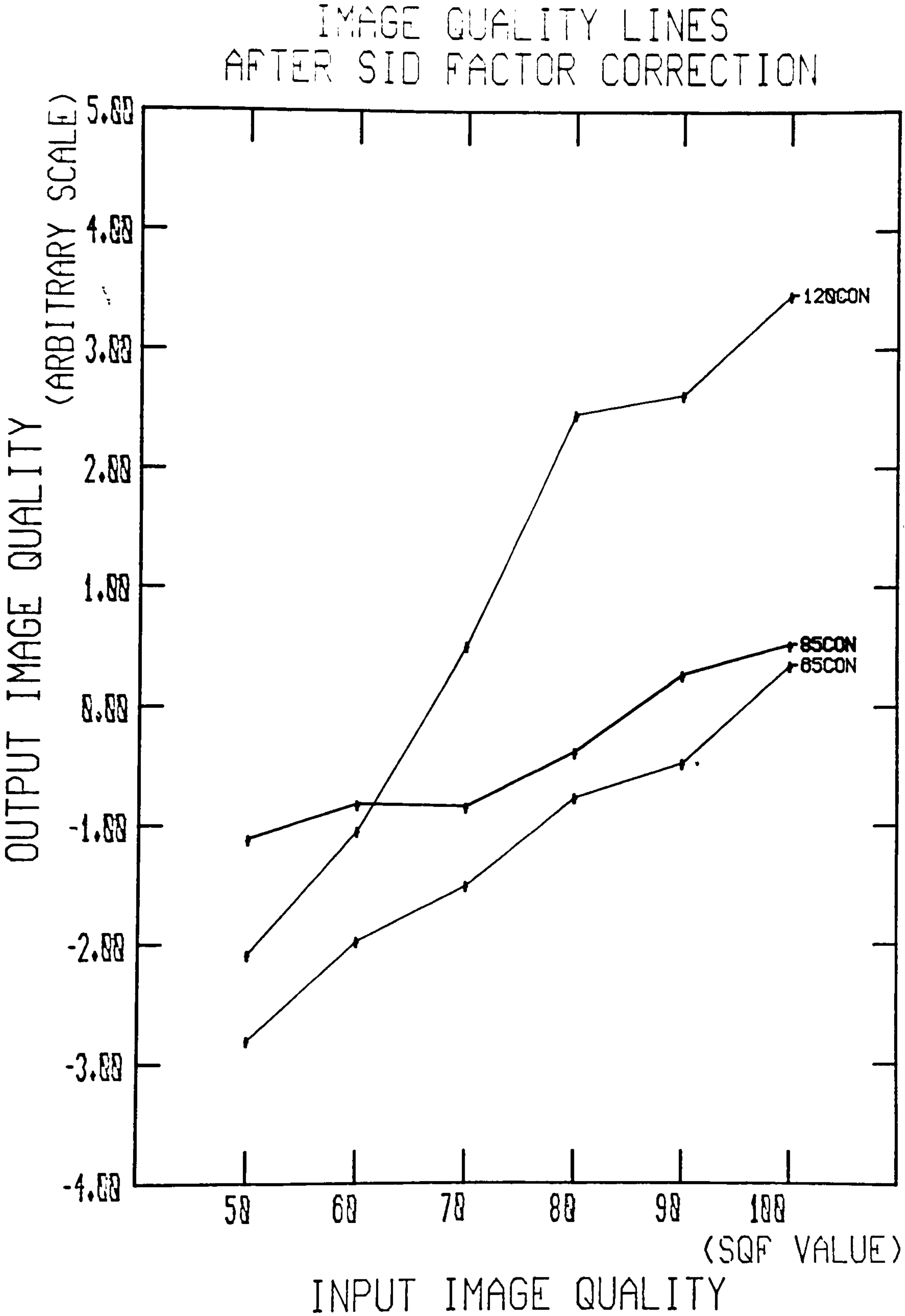


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
120CON
85CON
65CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 10

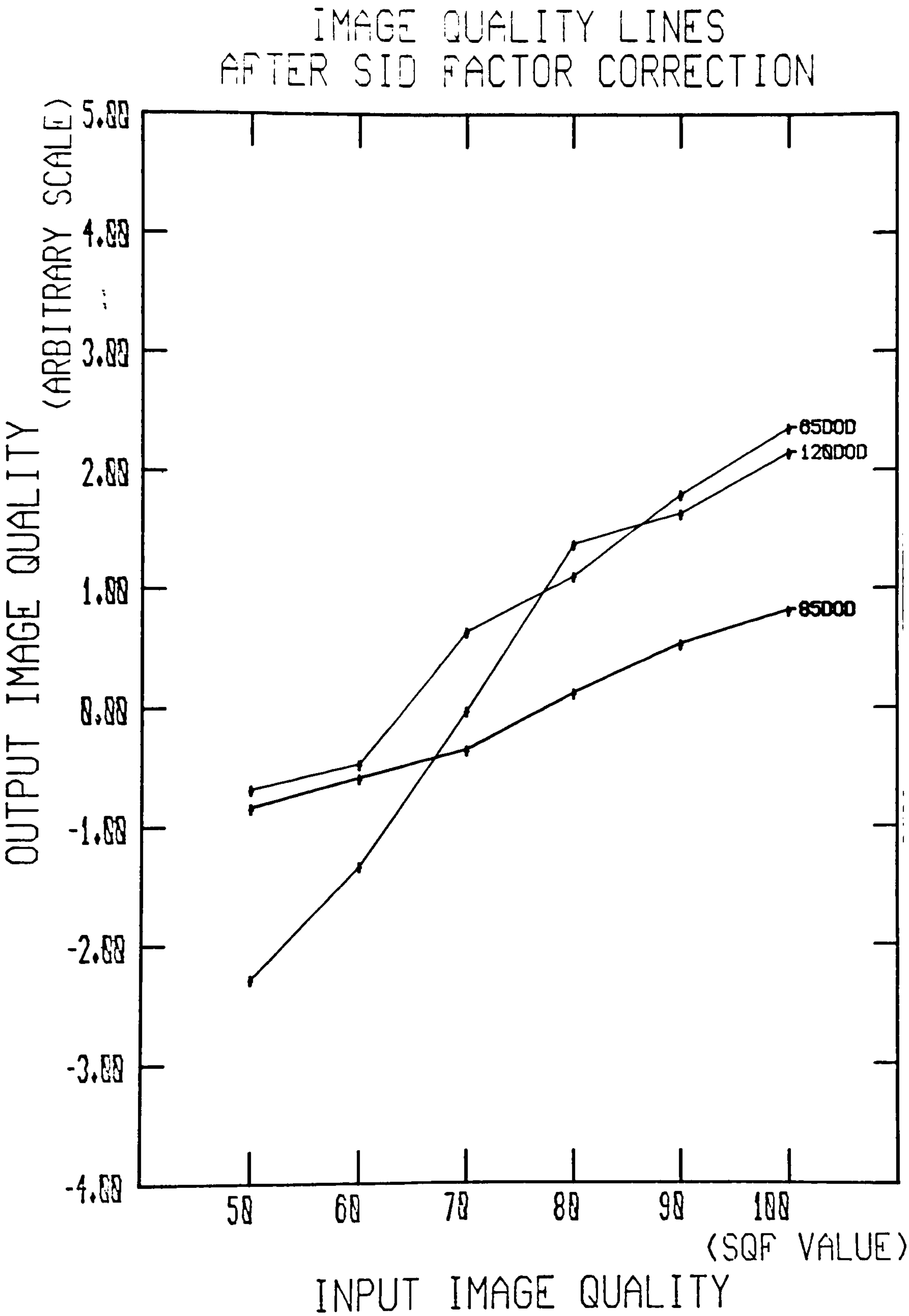


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY
(ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
65DOD
120DOD
85DOD
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 11

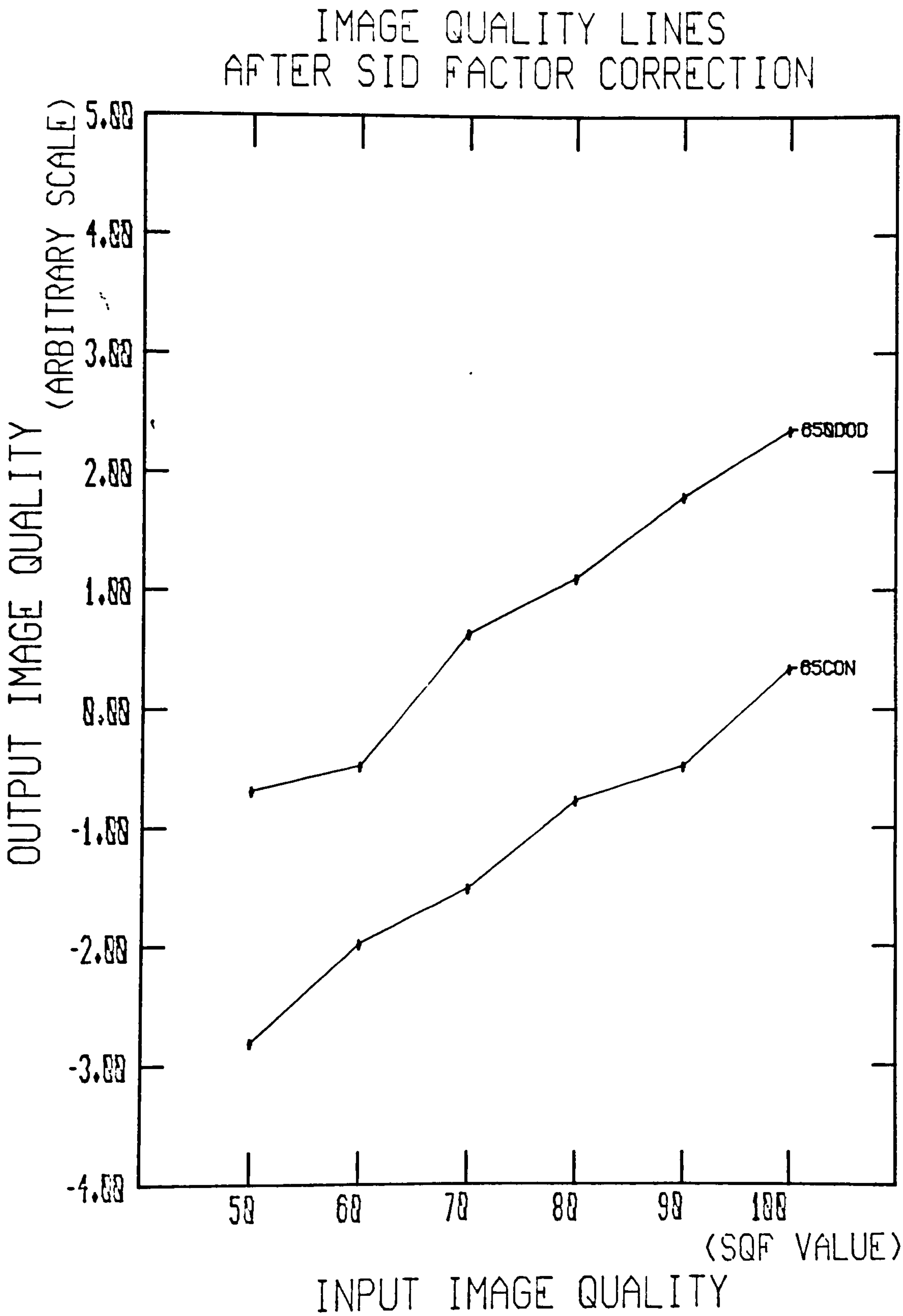


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY
(ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
65DOD
65CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 12

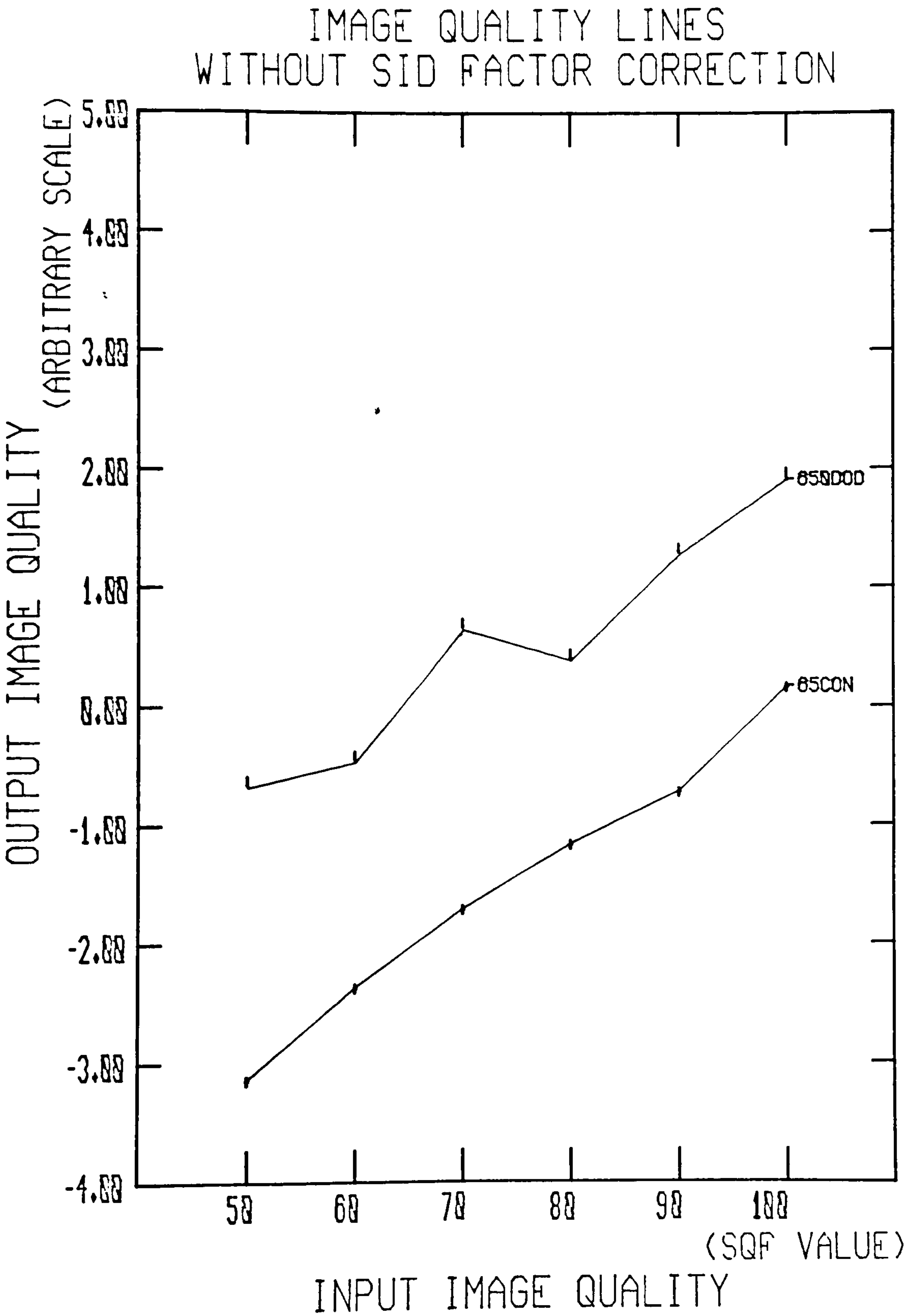


IMAGE QUALITY LINES
WITHOUT SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
65ODOD
65CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 13

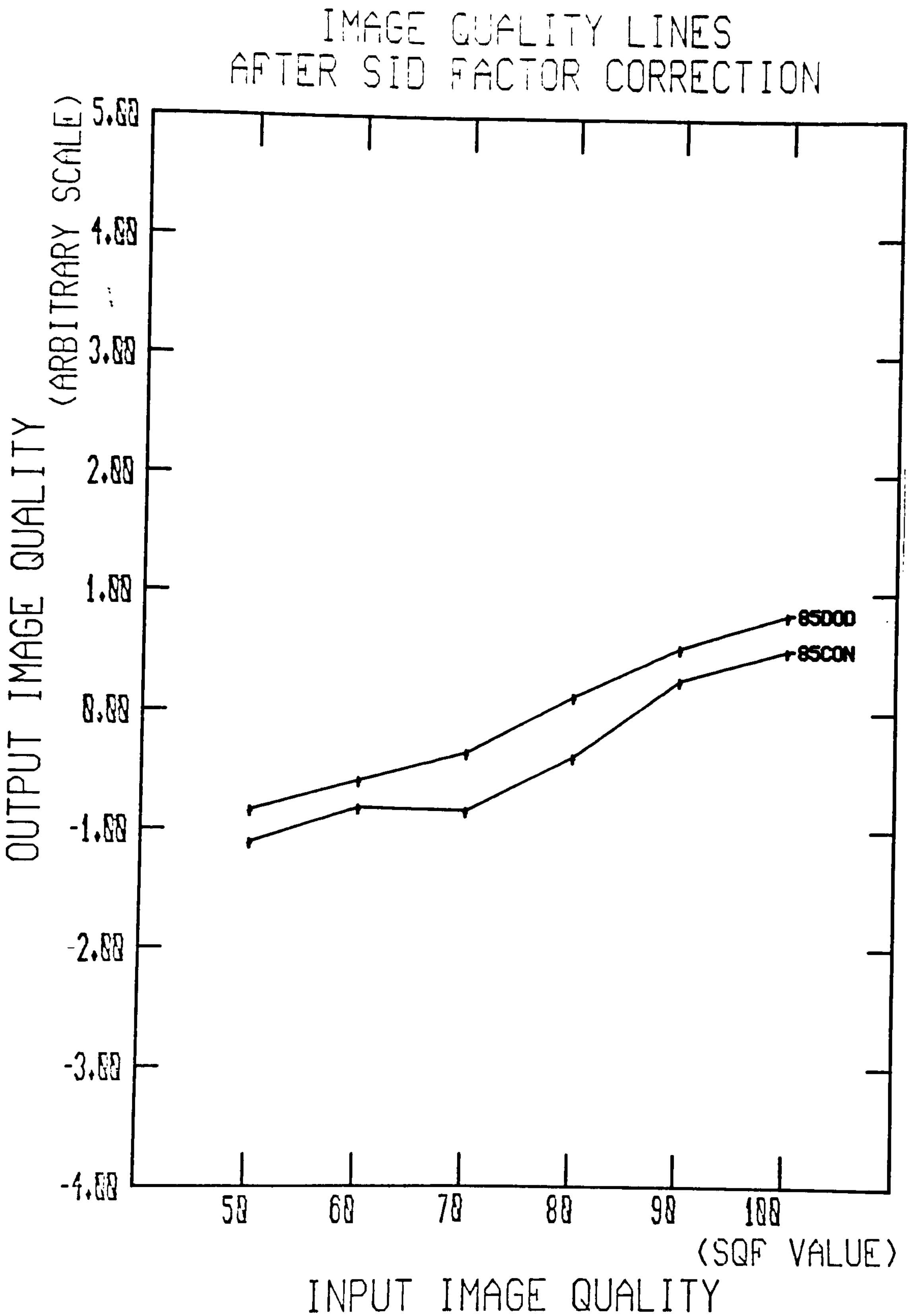


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY
(ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
85DOD
85CON
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 14

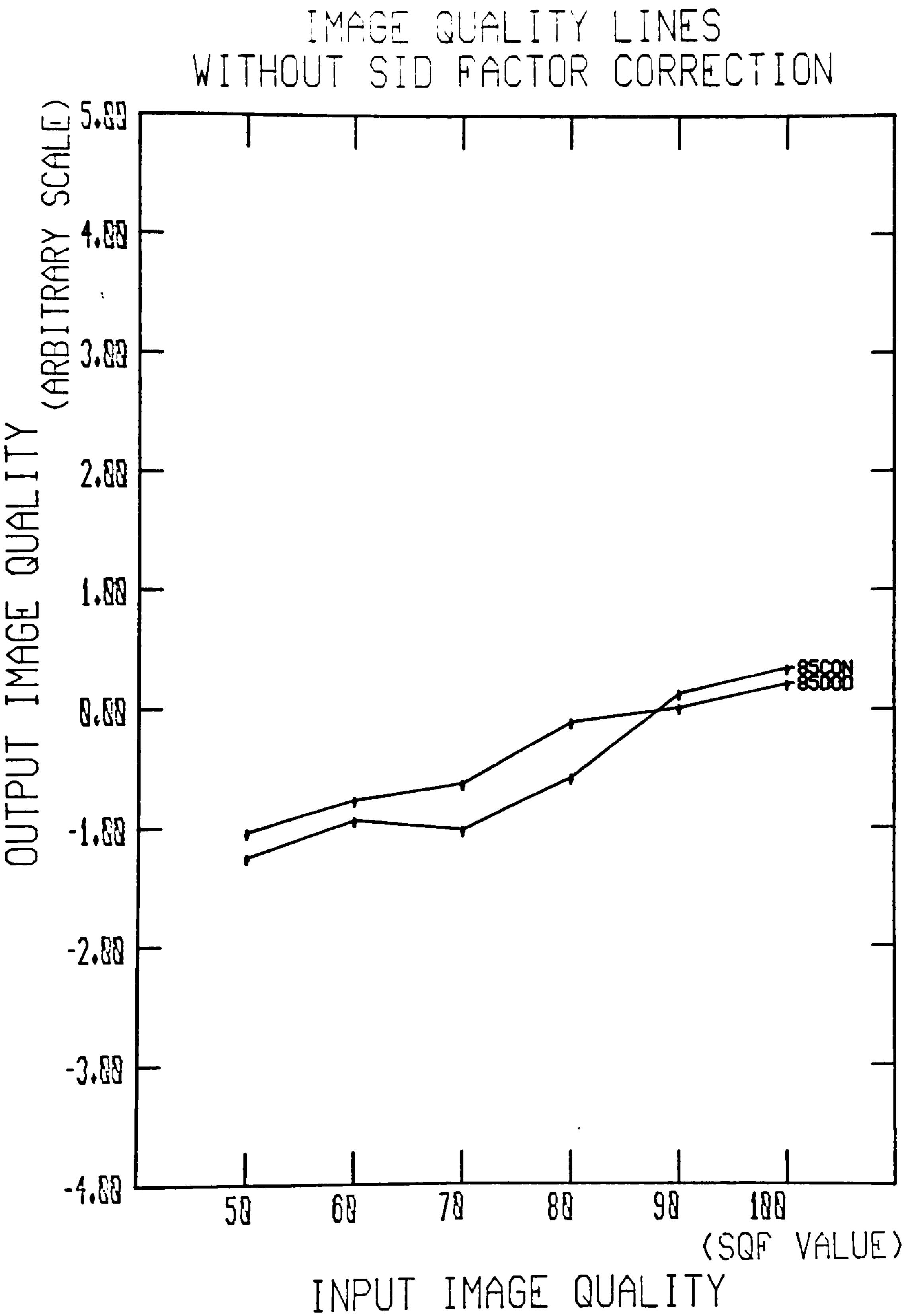


IMAGE QUALITY LINES
WITHOUT SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY
85CON
85DOD

Figure 15

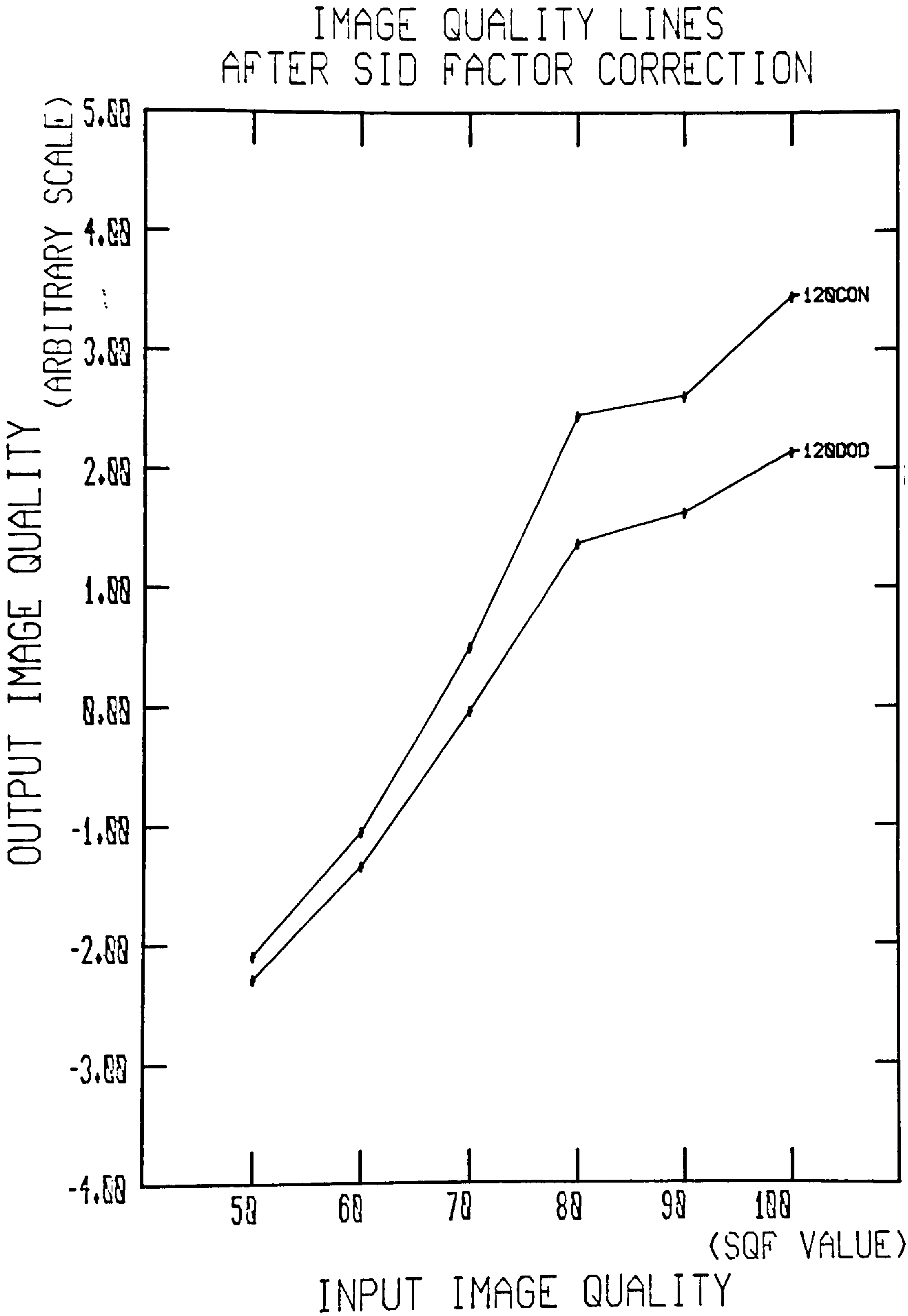


IMAGE QUALITY LINES
AFTER SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY
(ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
120CON
120DOD
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 16

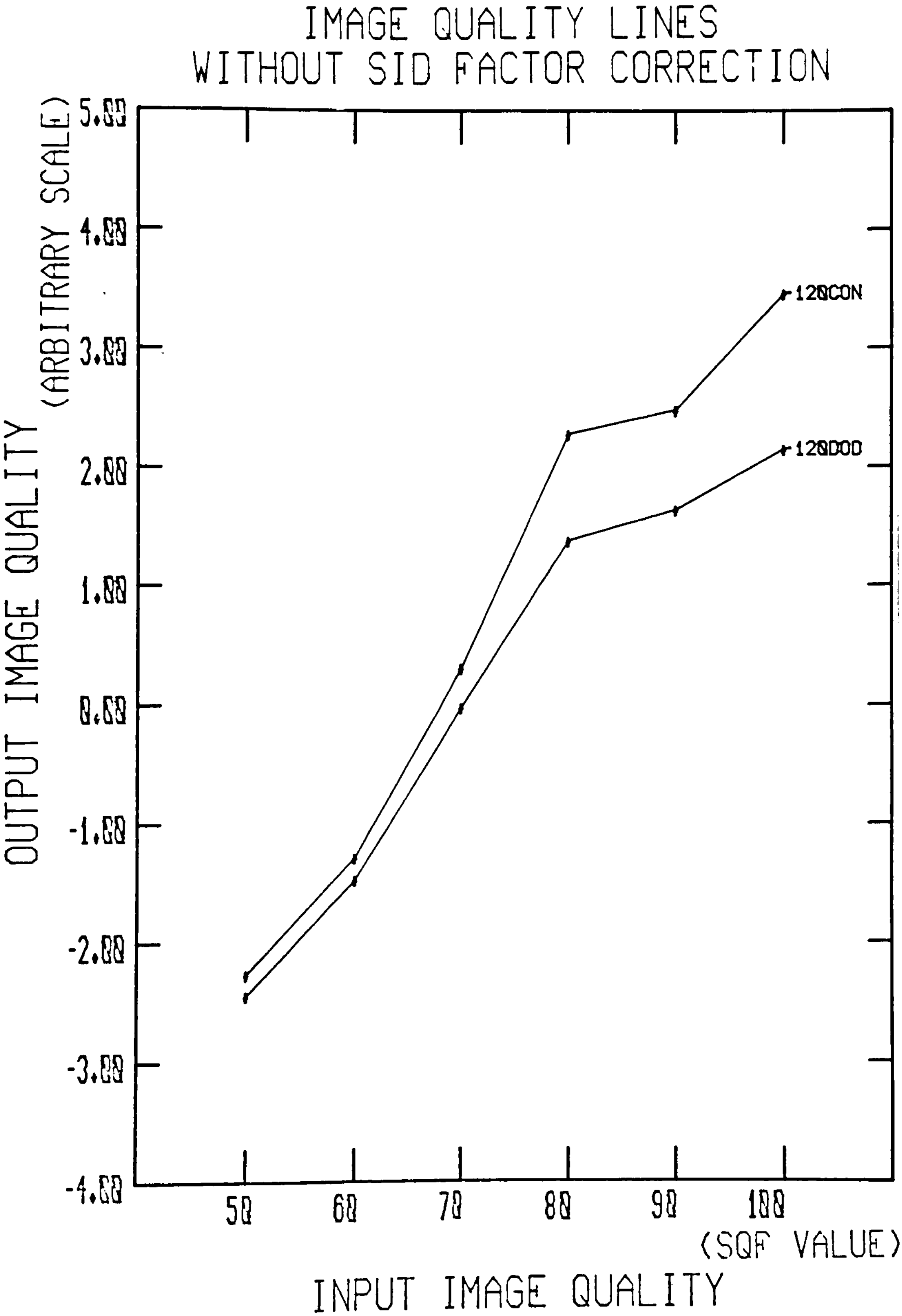


IMAGE QUALITY LINES
WITHOUT SID FACTOR CORRECTION
OUTPUT IMAGE QUALITY (ARBITRARY SCALE)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
120CON
120DOD
50
60
70
80
90
100
(SQF VALUE)
INPUT IMAGE QUALITY

Figure 17

The slope of the image quality line is used as an indicator to show the sensitivity of the reproduced image quality with respect to the input image quality. In other words, when an image quality line has a steeper slope, under the same reproduction situation, the quality of the reproduction is more sensitive to the quality of the original. A slight change of input image quality can drastically change the reproduction quality. In examining the slope values (m value) of each case in this study, it is determined that they are closely grouped together with the same screen frequency regardless of the reproduction technique that had been used. Screen frequency of a 120 lines/inch has the greatest slop, 65 indicates a modest slope, and the 85 has the least slope. In order to explain this phenomenon, it is assumed that at a high screen frequency, the potential to maintain detail in the reproduction is greater. For poor quality originals, there is little detail that can be preserved in the reproduction. Therefore, the advantage of using a high screen frequency does not exist. Also, due to the small size of the halftone dots at a high screen frequency, the ink-fill in problem which causes dot gain becomes severe for multicolor printing. The degradation on reproduced image quality becomes more noticeable. For these reasons, the screen frequency of a 120 lines/inch is the one which is most sensitive to the input image quality. As the screen frequency becomes lower, a reversal happened. The 65 lines/inch reproduction has a deeper slope than the 85 lines/inch. It is hypothesized that at a high screen frequency, human vision can not resolve the texture of the halftone dots under the normal viewing distance. The quality of the input image is the dominant factor that controls the quality of the reproduction. As the screen frequency becomes lower, the sharp edge of the halftone dots create an illusion to the observer's perceived impression about the quality of the reproduced image. Hence, significant improvement in the sharpness of the output image is possible by this "illusion". As the screen frequency varies from high to low, there is a transition region. Over this region, the proportion which attributed to the quality of the reproduction between the quality of the original and reproduction screen frequency changed. Screen frequency becomes a more important factor in affecting the final reproduction quality. The shallow slopes of the 85 lines/inch screen frequency indicates that the transition region is somewhere around this screen frequency.

In addition to reviewing the results from the screen frequency and input image quality, other aspects, such as the effect of reproduction techniques on the final image quality was also investigated. Reproductions using the conventional multiangle halftone printing found that the quality of the reproduction follows the order of screen frequency (Figure 10). Good reproduction is associated with high screen frequency. Even though there are some disagreements between judges at the cases where input image quality was poor. The overall pattern still holds for this trend. Reproduction quality does not follow this order when the Dot-on-Dot techniques was used. The screen frequency of 65 lines/inch has the best image quality over the whole range of screen rulings. It is believed that as the halftone dots reach a certain size, better control of the registration during printing can be achieved easier. Registration control is the crucial factor to the success of using the Dot-on-Dot technique. Once the registration is in control, the advantage of Dot-on-Dot technique such as being free of the Rosette pattern, produces a sharper image. This assumption is further supported by comparing the image quality lines of these two reproduction techniques at the same screen frequency (Figure 12, 14, and 16). Dot-on-Dot has the better reproduction quality on two of the lower frequencies. The differences between the two techniques become smaller as the screen frequency goes higher. Once it is over the transition region, conventional technique becomes the preferred method.

In relating the results of this study to the four original hypothesis, what the evidence indicates is that the quality of the halftone color image does increase as the screen frequency increases regardless of the production technique used. In other words, the image scale appears lineal for all the screen frequencies that were studied. These finding denied the statements of the first and the third hypothesis. As we review the results from the relationship of output image quality and input image quality, the results also indicate that there is a linear relationship between these two factories, this kind of linear relationship exists on both conventional and Dot-on-Dot reproduction techniques. Due to these findings, hypothesis two and four were also denied. In reviewing the results of this study, one of the most interesting points discovered was that the varying "weight" of image quality and reproduction screen frequency these two factories in determining the quality of the final reproduction as the reproduction circumstances changed. In other words, in order to achieve the optimum reproduction of a specific original, predetermining of the reproduction circumstance is a must step.

VI. CONCLUSION AND SUGGESTION

A. Summary and Conclusions:

The gain in qualitative terms of image quality by using the Dot-on-Dot technique has long been observed, but nobody has quantified the difference between conventional four screen-angles and Dot-on-Dot single screen-angle printing techniques. The result of this study provides a quantitative relation between these two reproduction techniques at various screen frequencies. Moreover, by employing these quantitative relations, the choice of a reproduction method for a given circumstance become less arguable and the result is more predictable.

Chantana Tangesee stated in her paper, " The image quality scale appears linear all the way down in terms of overall image quality of black and white halftone prints. .... For color halftone prints, the result may or may not follow this. " The results of this study confirm the linearity of image quality hold true for color halftone printing regardless of the arrangement of screen angle. Summarizing the results of the preceeding analysis, Dot-on-Dot is preferable to conventional technique at lower screen frequency. Under different reproduction circumstances, input image quality and reproduction screen frequency have different weight toward determining the quality of the final reproduction.

B. Suggestion for Future Studies

Ink density is an important factor which attributes to the quality of the reproduction. It is also a variable which is hard to control during printing. The purpose of using the CROMALIN off-press proofing method was to eliminate the variable of density difference so that the final image density would have no effect on the reproduced image quality. Beyond this original expectation, images reproduced by CROMALIN showed a wide range of density variation in the shadow area. Since ink density was not one of the variables in this study, a correction factor-Solid Ink Density factor was designed to eliminate the effect of this variable. Certain assumptions were made for simplification purpose. Although the results were very encouraging, the validity of using a solid ink density factor obtained from the black and white images on multicolor halftone images is still questionable. A further investigation can be designed to determine the relationship between the maximum ink density of a multicolor halftone image and the quality of this image.

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APPENDIX A

CALCULATIONS OF DEFOCUS

The arrangement of inducing different degrees of defocusing into images is illustrated in Figure 18. The Position I diagram represents the situation that normally would be used for reproducing an image. A sharp image of the original is formed at the image plane where the unexposed film is placed. The magnification (M1) is determined by the ratio between the image distance (S1') and the object distance (S1) or the ratio between the image size (H1') and the object (original) size (H).

$$M1 = \frac{S1'}{S1} = \frac{H1'}{H}$$

By moving the original closer to the lens with a distance (Do), is illustrated in the Position II diagram. The image plane where the sharp focused image is formed will move further away from the lens. If an image is formed at the new position, it will have a different magnification as in the Position I situation ($M2 \neq M1$). For this study, the image size was kept the same for all occations. In order to maintain the image size, instead of setting at the sharp image plane, the unexposed film is placed at a position where the image distance is S2". The ratio between the new object distance (S2) and new image distance (S2") is the same as in the previous situation.

$$\frac{S2''}{S2} = \frac{S1'}{S1} = \frac{H1'}{H} = \frac{H2''}{H}$$

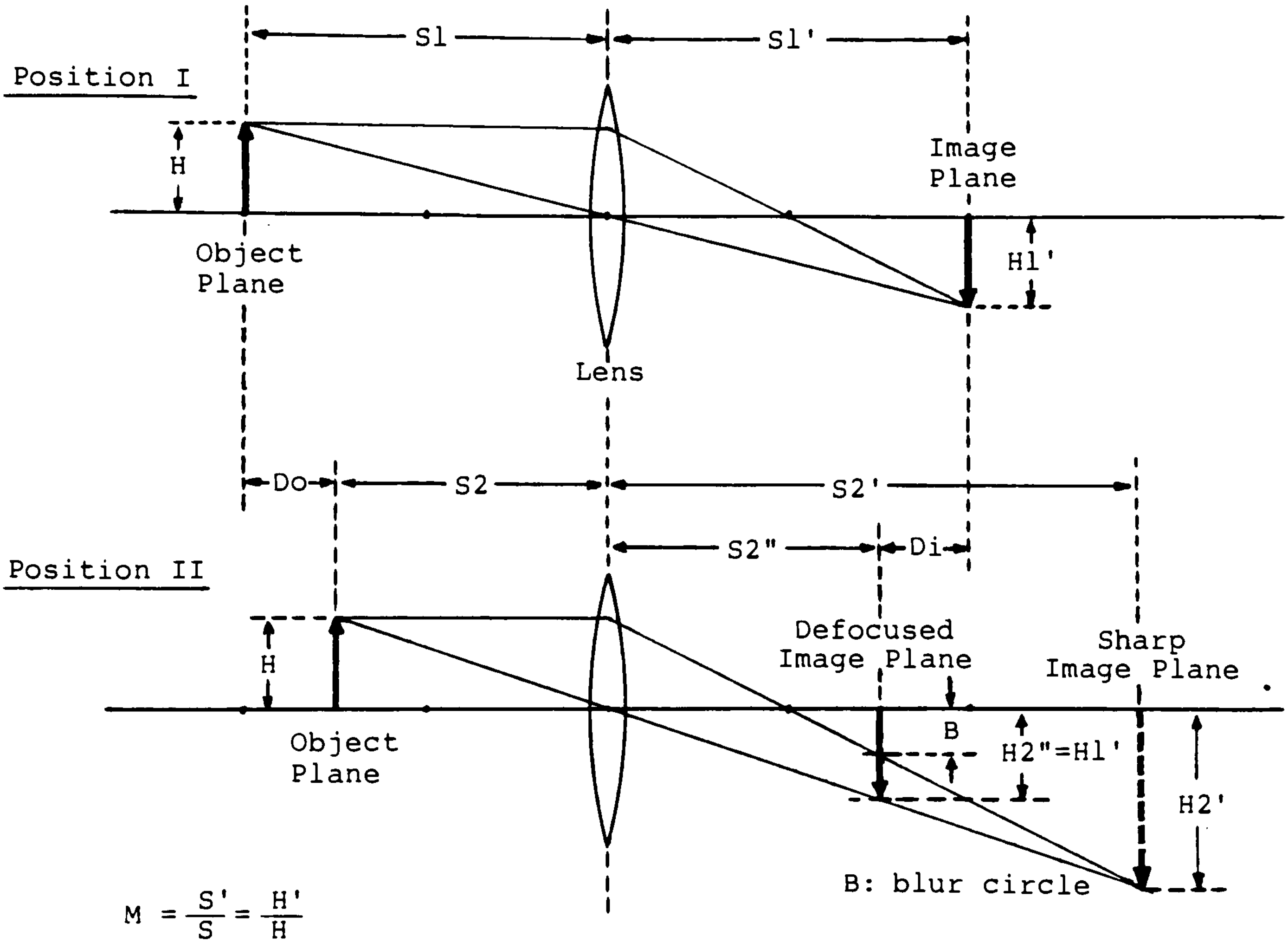

Figure 18: Diagram showing the relationship between object plane, image plane of sharp focus, and the defocused image plane with a blur circle diameter of B.

The distance of shift between S2" and S2 is Di. For a one-to-one reproduction, Do and Di are equal. After this manipulation, the unexposed film is not located at the sharp focal plane. Therefore, certain degrees of defocusing is induced into the reproduced image. The degree of defocusing is measured by the diameter of the blur circle (B). The larger the blur circle, the greater the amount of defocus.

In order to determine that a reproduced image has the desired SQF value, is by means of the diameter of the blur circle. A correlation between the SQF value and the diameter of the blur circle must be formed first. Since SQF is derived from the system MTF curve. A function which has the ability to describe the work of the system should be specified. The Cylinder function which is uaually used to describe the transmittance of a circular aperture is the appropriate one. Its Fourier transform is the Sombrero function (Figure 02). Their relationship is described as follows:

$$\frac{1}{b^2}\mathrm{Cyl}\left(\frac{r}{b}\right) \Longleftrightarrow \frac{\pi}{4}\mathrm{Somb}(bf)$$

Where f is the spacial frequency, and b is the scale factor that is usually proportional to the 'width' of the function.[16] The MTF of this imaging system then can be approximated as follows:

$$\mathrm{MTF}(f) \approxeq \mathrm{Somb}(bf)$$

The SQF value is the integral of the Somb function between the spatial frequency bandpass that defined for SQF as stated in the main text. The only parameter in the above equation which will change the SQF value is the scale factor b. The shape of a MTF curve is affected by the b value, so as the area under the MTF curve. Figure 20 illustrated this relationship.

The SQF is then plotted as a function of b (Figure 21). This curve tells us exactly what b value to use for a specific function, in order to get the desired SQF value as ancoded into the reproduced image.

The diameter of the blur circle is a linear function of the scale factor when an image is formed at the sharp image plane. The b value (bl) is equal to 1. Theoretically, when there is no blur circle under this type of situation, the B value is then specified as 0. Under any other situation, images are formed at the defocused planes. From the calculation of magnification, the new b values (b2, b3, --- etc.) can be specified.

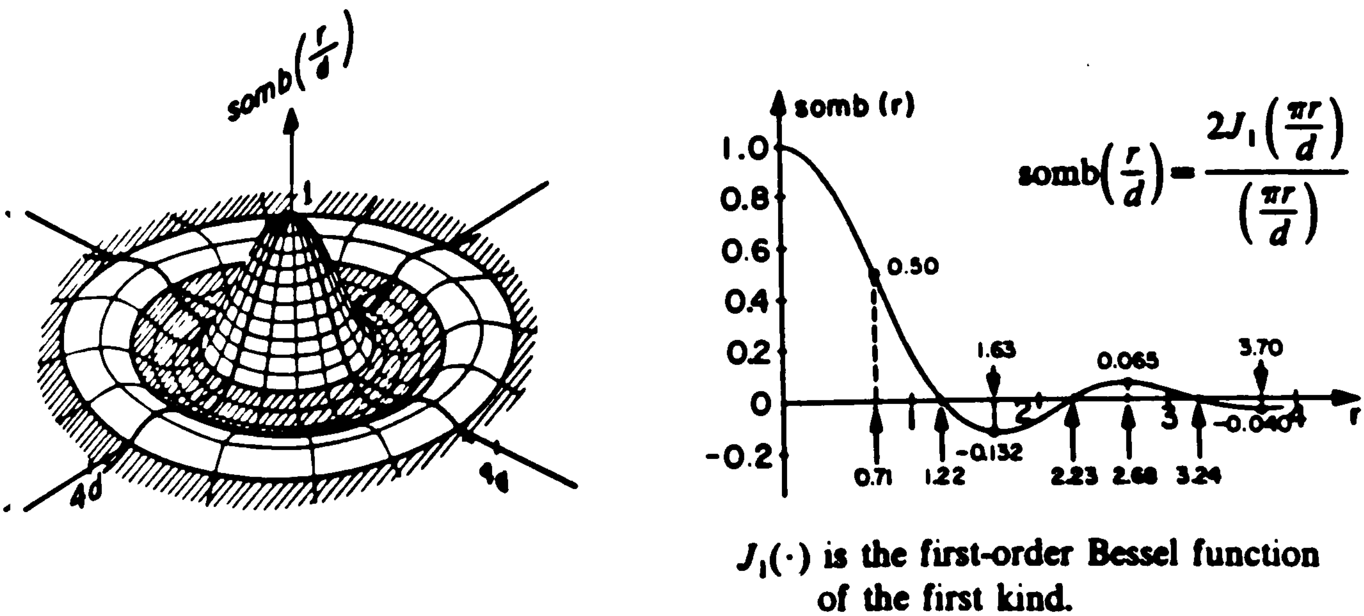

Figure 19: The Sombrero Function

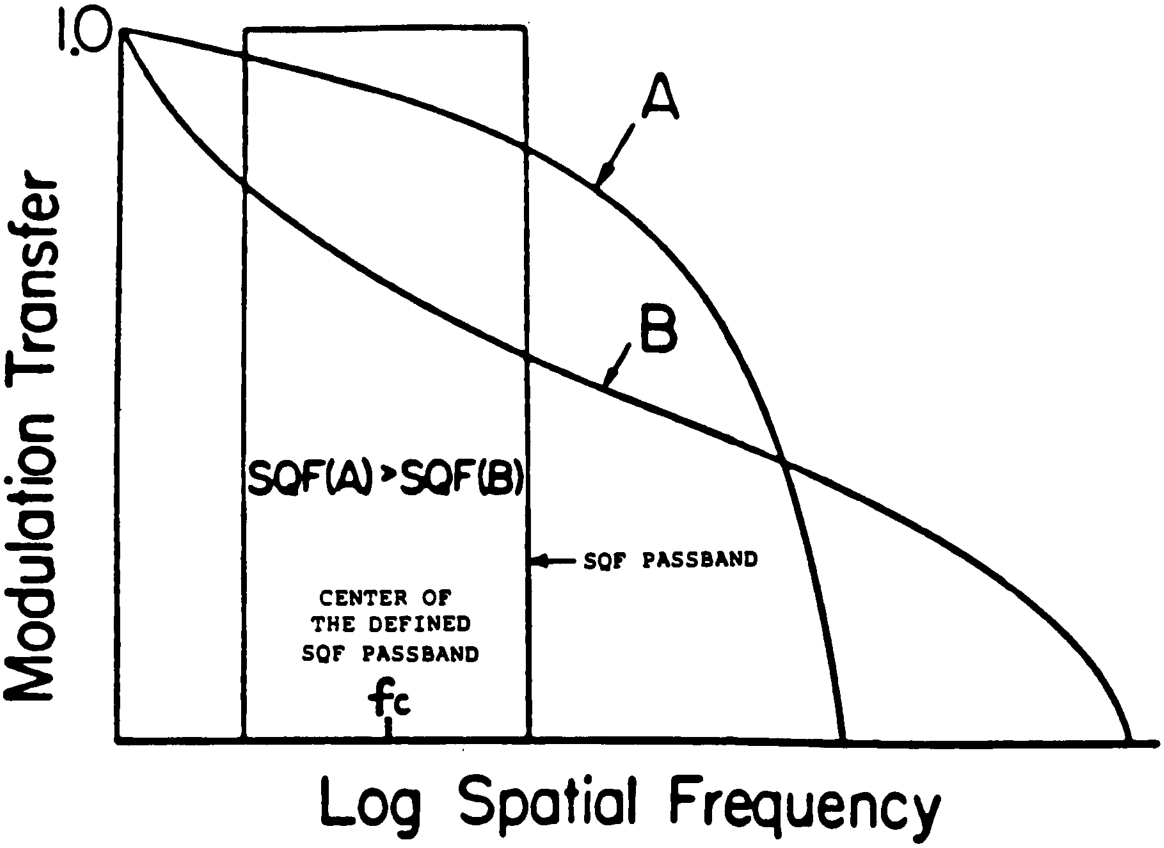

Figure 20: The relationship of MTF curve and b value

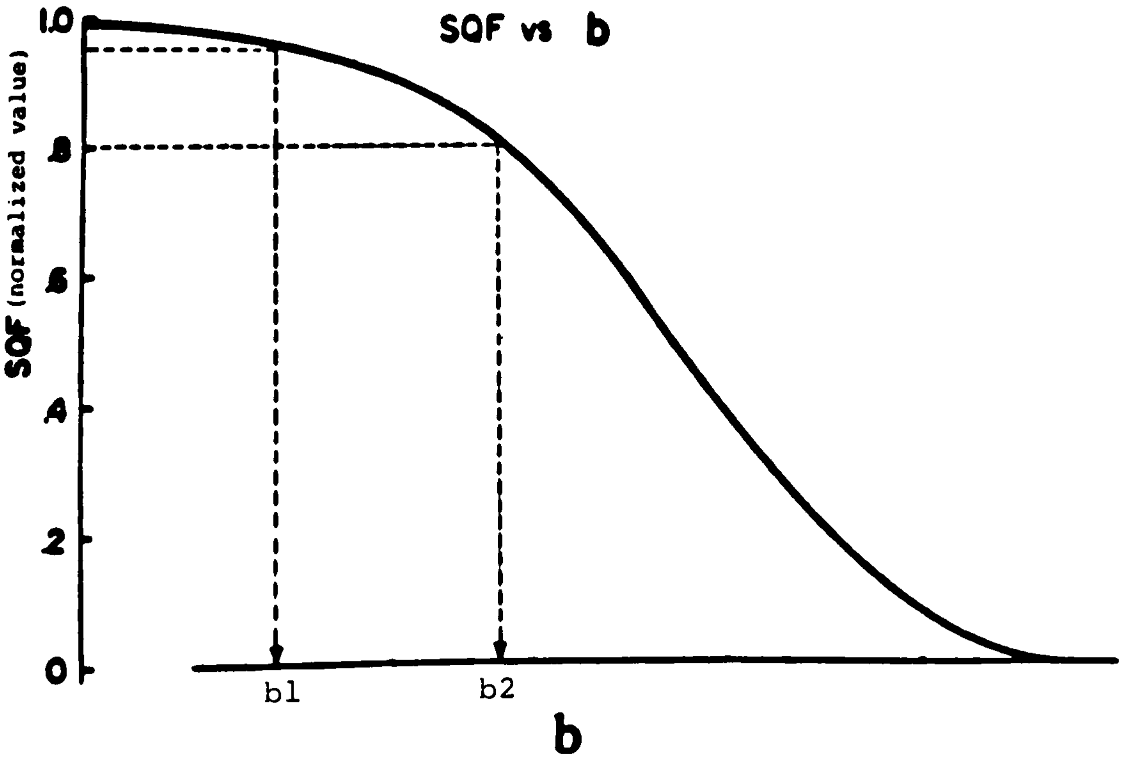

Figure 21: SQF Template

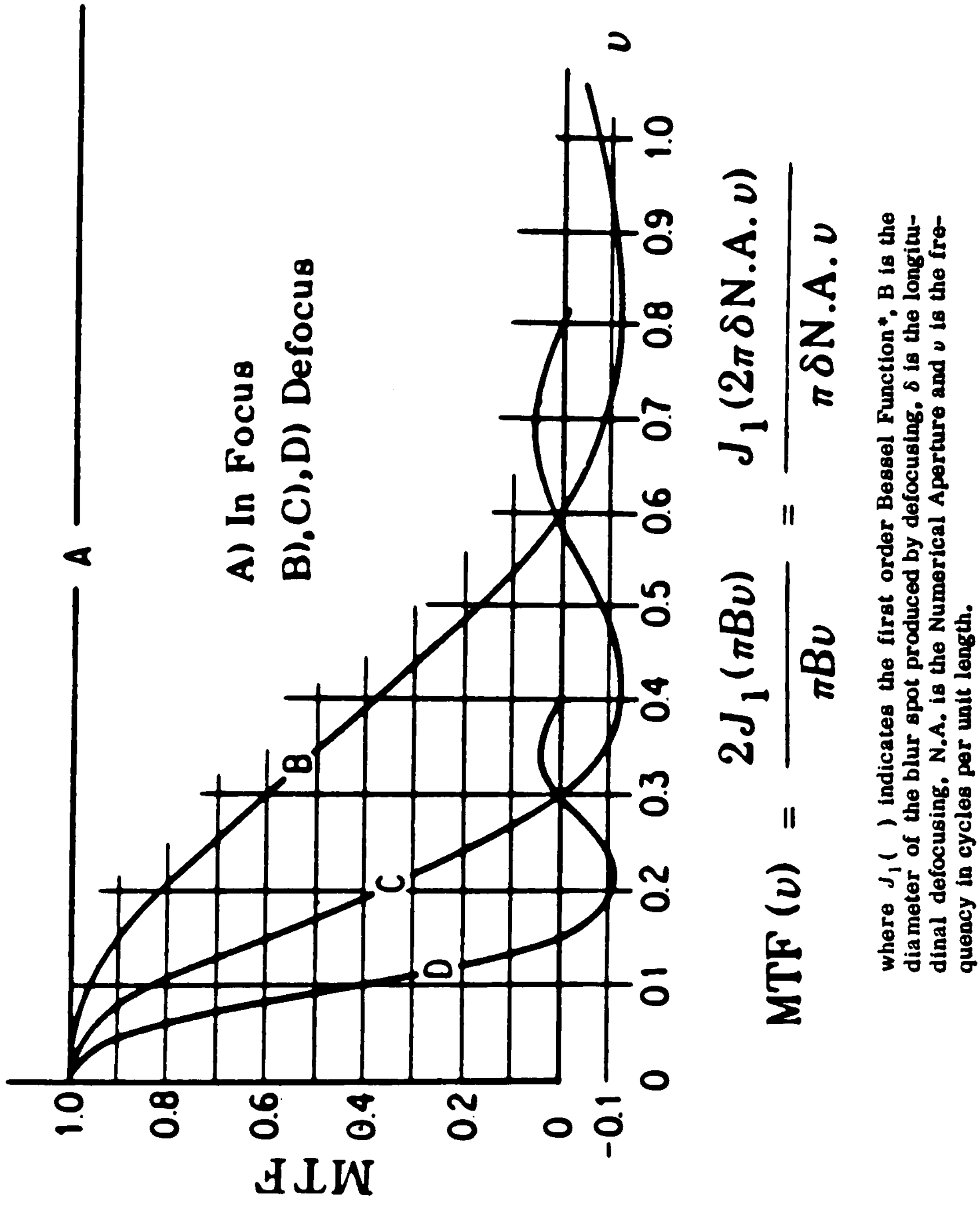

Figure 22: The effect of defocusing on the modulation transfer function

APPENDIX B

CALCULATION OF S.I.D. CORRECTION FACTOR

For the calculation of Solid Ink Density correction factor, the first step is to determine the scaling ratio between Wu's study and this experiment on the output image quality scale. This ratio is used to calculate the correction value at various maximum ink densities in this study.

The image quality line of screen frequency 65, Dot-on-Dot reproduction, at the two data points where the input image quality is SQF 70 and SQF 80, has a discontinuous jump (Figure 23). As we exame the maximum ink density values of every single data point on this image quality line, the Dmax value of data points are: SQF 50, 60, and 70 are found grouped together. For the data points of SQF 80, 90, and 100, the Dmax values form another group. Due to this unsmooth phenomenon of this image quality line, it was used to calculate the scaling ratio.

By using the data points of SQF 50, 60, and 70. A linear regression line was determined. Once the linear regression was obtained, the value of data point SQF 75 can be derived from this regression line. Applying the same procedure for data points SQF 80, 90, and 100, another linear regression line was determined. From this regression line, the value of SQF 75 was also determined (Figure 24). Since these two regression lines were determined by two different groups of data for the same data point SQF 75, two values were determined. The difference

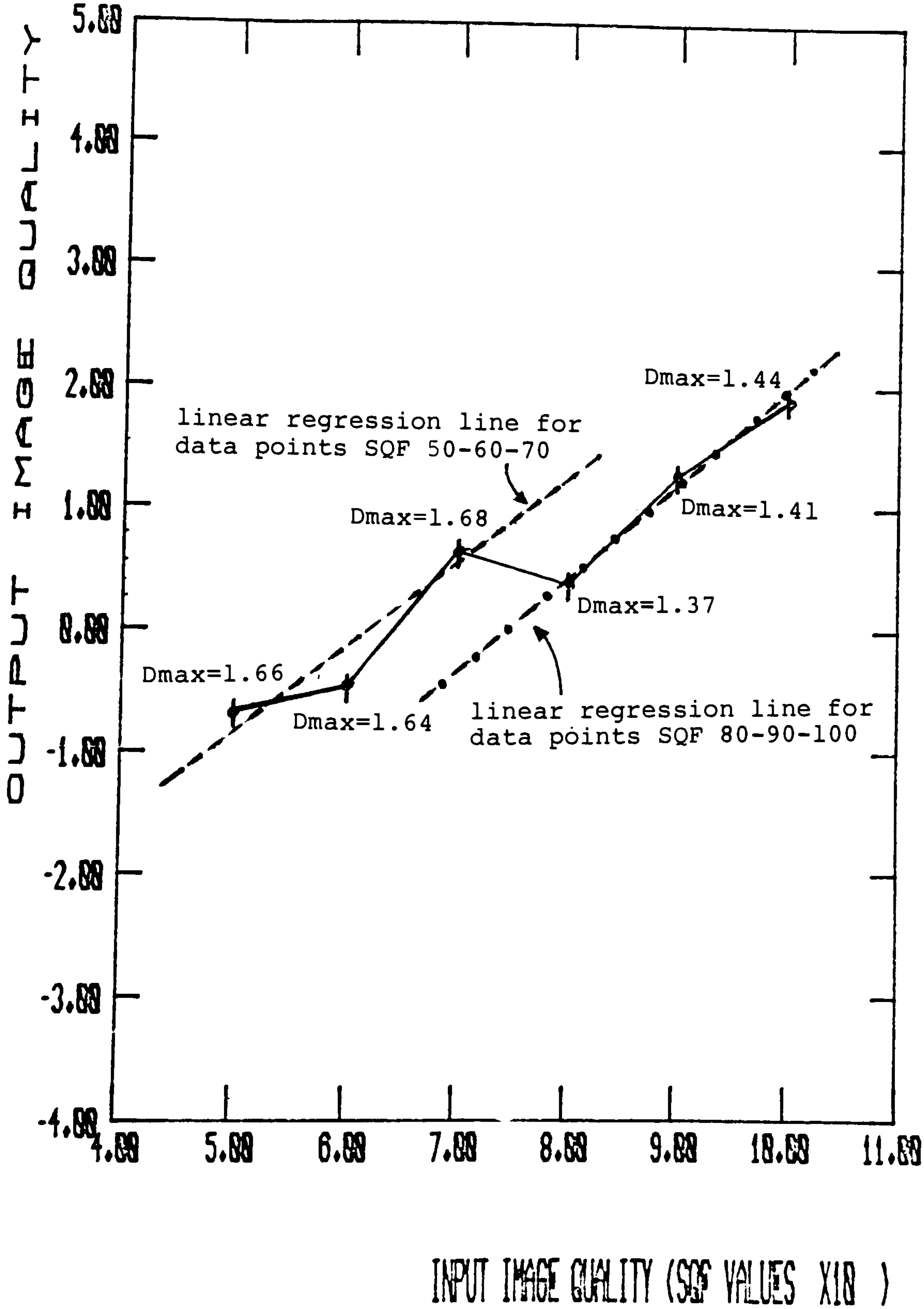

Figure 23: Linear regression line of screen frequency 65, Dot-on-Dot reproduction.

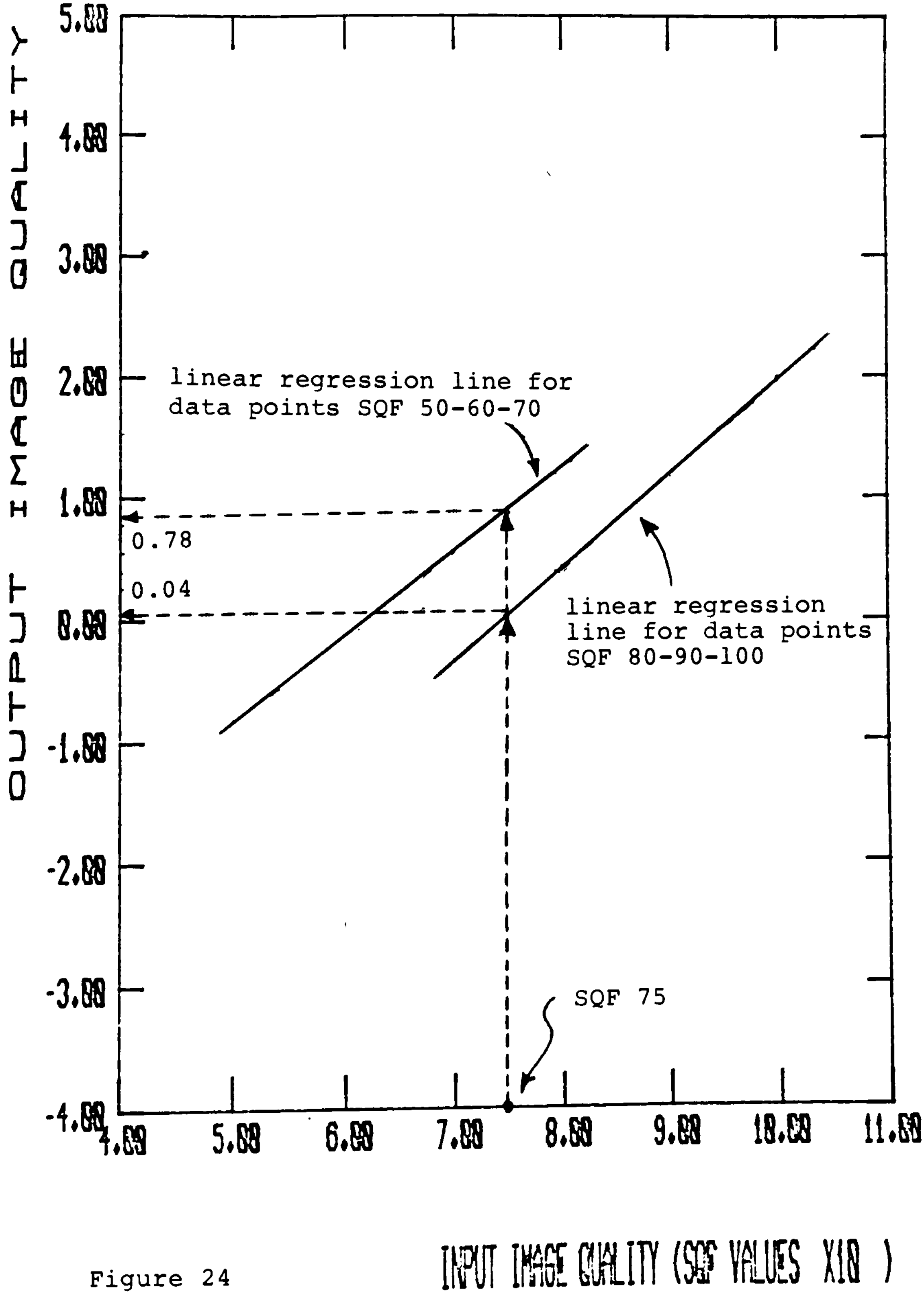
OUTPUT IMAGE QUALITY
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
linear regression line for data points SQF 50-60-70
0.78
0.04
linear regression line for data points SQF 80-90-100
SQF 75
INPUT IMAGE QUALITY (SQF VALUES X10)

Figure 24

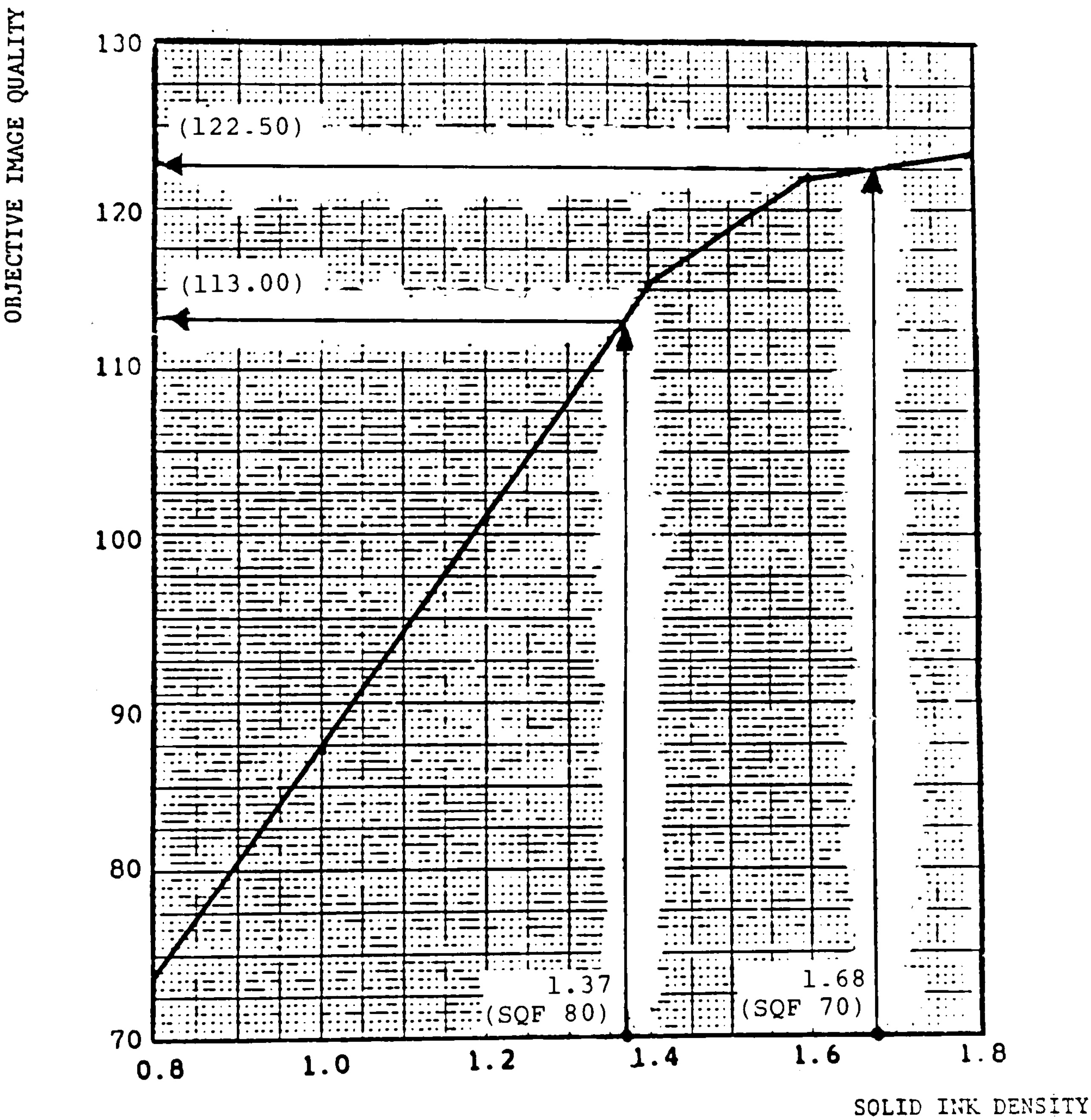

Figure 25 The relationship between image quality and solid ink density

between these two values (delta = 0.78) represents the quality differencse which is caused by the differences in maximum ink dendity in this study.

Since the discontinuous jump section of the 65, Dot-on-Dot image quality line was between the data points of SQF 70 and 80. Taking the density values of these two points, and look up the corresponding points on Wu's graph (Figure 25). Tracing these two points back to the curve, the appropriate value of objective image quality was determined. The difference of these two values (delta = 9.5) also represents the quality difference which cause by the difference in solid ink density.

As we divide the delta value of this study by the delta value from Wu's curve, the resulting value is the scale ratio between the two image quality scales (S.R.=0.082). For every one scale unit changes in Wu's study, there are 0.082 scale unit changes in this study. Hence, the value 0.082 is then used to calculate the corrention value at different solid ink densities.

Since the solid ink density 1.60 was considered as the optimum density for reproduction, the density has little affect on output image quality once the density value is higher than this point. Thus, the density 1.60 was decided as the cut-off point for correction. Any data point with the density value below 1.60 was corrected by this correction factor.

For the purpose of explaining, the data point of sqf 80, (Dmax = 1.37) is used as an example to demonstrate how to employe the correction factor into the original data set. On Wu's graph, a solid ink density of 1.37 is 113 on the objective image quality graph. For a solid ink density of 1.60, the objective image quality is 121.96. The objective quality difference between these two densities is 8.96. Using this value times the scaling ratio (8.96*0.082 = 0.73), this is the value to corrected the image quality at the data point SQF 80 where the density is 1.37. Before the addition of the correction factor , the output image quality was 0.38. As we add up the correction value 0.73, the "CORRECTED" output image quality becomes 1.11. The same procedure was applied to all data points where their maximum density was below 1.60.

APPENDIX C

EVALUATION SHEET   Sample Set No. 1

* Please make a check mark apposite the one which you "PREFER"
* According to your own judgement, please give a score to indicate their "DIFFERENCE", on a scale from 1 to 10.

10 means "VERY DIFFERENT"
1 means "VERY CLOSE"
0 means "NO DIFFERENCE"

GROUP # 1	GROUP # 2	GROUP # 3
___A(vs)B ___ -->[ ]	___G(vs)H___ -->[ ]	___G(vs)F ___ -->[ ]
___A(vs)C ___ -->[ ]	___G(vs)I___ -->[ ]	___G(vs)J ___ -->[ ]
___A(vs)D ___ -->[ ]	___G(vs)J___ -->[ ]	___G(vs)E ___ -->[ ]
___A(vs)E ___ -->[ ]	___G(vs)K___ -->[ ]	___G(vs)L ___ -->[ ]
___A(vs)F ___ -->[ ]	___G(vs)L___ -->[ ]	___G(vs)A ___ -->[ ]
___B(vs)C ___ -->[ ]	___H(vs)I___ -->[ ]	___F(vs)J ___ -->[ ]
___B(vs)D ___ -->[ ]	___H(vs)J___ -->[ ]	___F(vs)E ___ -->[ ]
___B(vs)E ___ -->[ ]	___H(vs)K___ -->[ ]	___F(vs)L ___ -->[ ]
___B(vs)F ___ -->[ ]	___H(vs)L___ -->[ ]	___F(vs)A ___ -->[ ]
___C(vs)D ___ -->[ ]	___I(vs)J___ -->[ ]	___J(vs)E ___ -->[ ]
___C(vs)E ___ -->[ ]	___I(vs)K___ -->[ ]	___J(vs)L ___ -->[ ]
___C(vs)F ___ -->[ ]	___I(vs)L___ -->[ ]	___J(vs)A ___ -->[ ]
___D(vs)E ___ -->[ ]	___J(vs)K___ -->[ ]	___E(vs)L ___ -->[ ]
___D(vs)F ___ -->[ ]	___J(vs)L___ -->[ ]	___E(vs)A ___ -->[ ]
___E(vs)F ___ -->[ ]	___K(vs)L___ -->[ ]	___L(vs)A ___ -->[ ]

Judge's Name: ______________________

Experienced( )   General( )

Today's Date: _____/_____/_____

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Sample Set No. 1

@Test Samples Screen Frequency :( )lines/inch

@Group # 1 samples represent :( )

Group # 2 samples represent :( )

EVALUATION SHEET   Sample Set No. 2

* Please make a check mark apposite the one which you "PREFER"
* According to your own judgement, please give a score to indicate their "DIFFERENCE", on a scale from 1 to 10.

  10 means "VERY DIFFERENT"

  1 means "VERY CLOSE"

  0 means "NO DIFFERENCE"

GROUP # 1	GROUP # 2	GROUP # 3
___A(vs)B ___ -->[ ]	___G(vs)H___ -->[ ]	___H(vs)F ___ -->[ ]
___A(vs)C ___ -->[ ]	___G(vs)I___ -->[ ]	___H(vs)L ___ -->[ ]
___A(vs)D ___ -->[ ]	___G(vs)J___ -->[ ]	___H(vs)A ___ -->[ ]
___A(vs)E ___ -->[ ]	___G(vs)K___ -->[ ]	___H(vs)I ___ -->[ ]
___A(vs)F ___ -->[ ]	___G(vs)L___ -->[ ]	___H(vs)C ___ -->[ ]
___B(vs)C ___ -->[ ]	___H(vs)I___ -->[ ]	___F(vs)L ___ -->[ ]
___B(vs)D ___ -->[ ]	___H(vs)J___ -->[ ]	___F(vs)A ___ -->[ ]
___B(vs)E ___ -->[ ]	___H(vs)K___ -->[ ]	___F(vs)I ___ -->[ ]
___B(vs)F ___ -->[ ]	___H(vs)L___ -->[ ]	___F(vs)C ___ -->[ ]
___C(vs)D ___ -->[ ]	___I(vs)J___ -->[ ]	___L(vs)A ___ -->[ ]
___C(vs)E ___ -->[ ]	___I(vs)K___ -->[ ]	___L(vs)I ___ -->[ ]
___C(vs)F ___ -->[ ]	___I(vs)L___ -->[ ]	___L(vs)C ___ -->[ ]
___D(vs)E ___ -->[ ]	___J(vs)K___ -->[ ]	___A(vs)I ___ -->[ ]
___D(vs)F ___ -->[ ]	___J(vs)L___ -->[ ]	___A(vs)C ___ -->[ ]
___E(vs)F ___ -->[ ]	___K(vs)L___ -->[ ]	___I(vs)C ___ -->[ ]

Judge's Name:____________________

Experienced( )   General( )

Today's Date: ____/____/____

==

Sample Set No. 2

@Test Samples Screen Frequency :(   )lines/inch

@Group # 1 samples represent :(   )

Group # 2 samples represent :(   )

EVALUATION SHEET   Sample Set No. 3

* Please make a check mark apposite the one which you "PREFER"
* According to your own judgement, please give a score to indicate their "DIFFERENCE", on a scale from 1 to 10.

10 means "VERY DIFFERENT"
1 means "VERY CLOSE"
0 means "NO DIFFERENCE"

GROUP # 1	GROUP # 2	GROUP # 3
___A(vs)B ___ -->[ ]	___G(vs)H___ -->[ ]	___C(vs)K ___ -->[ ]
___A(vs)C ___ -->[ ]	___G(vs)I___ -->[ ]	___C(vs)D ___ -->[ ]
___A(vs)D ___ -->[ ]	___G(vs)J___ -->[ ]	___C(vs)J ___ -->[ ]
___A(vs)E ___ -->[ ]	___G(vs)K___ -->[ ]	___C(vs)F ___ -->[ ]
___A(vs)F ___ -->[ ]	___G(vs)L___ -->[ ]	___C(vs)I ___ -->[ ]
___B(vs)C ___ -->[ ]	___H(vs)I___ -->[ ]	___K(vs)D ___ -->[ ]
___B(vs)D ___ -->[ ]	___H(vs)J___ -->[ ]	___K(vs)J ___ -->[ ]
___B(vs)E ___ -->[ ]	___H(vs)K___ -->[ ]	___K(vs)F ___ -->[ ]
___B(vs)F ___ -->[ ]	___H(vs)L___ -->[ ]	___K(vs)I ___ -->[ ]
___C(vs)D ___ -->[ ]	___I(vs)J___ -->[ ]	___D(vs)J ___ -->[ ]
___C(vs)E ___ -->[ ]	___I(vs)K___ -->[ ]	___D(vs)F ___ -->[ ]
___C(vs)F ___ -->[ ]	___I(vs)L___ -->[ ]	___D(vs)I ___ -->[ ]
___D(vs)E ___ -->[ ]	___J(vs)K___ -->[ ]	___J(vs)F ___ -->[ ]
___D(vs)F ___ -->[ ]	___J(vs)L___ -->[ ]	___J(vs)I ___ -->[ ]
___E(vs)F ___ -->[ ]	___K(vs)L___ -->[ ]	___F(vs)I ___ -->[ ]

Judge's Name:______________________

Experienced( )   General( )

Today's Date: ____/____/____

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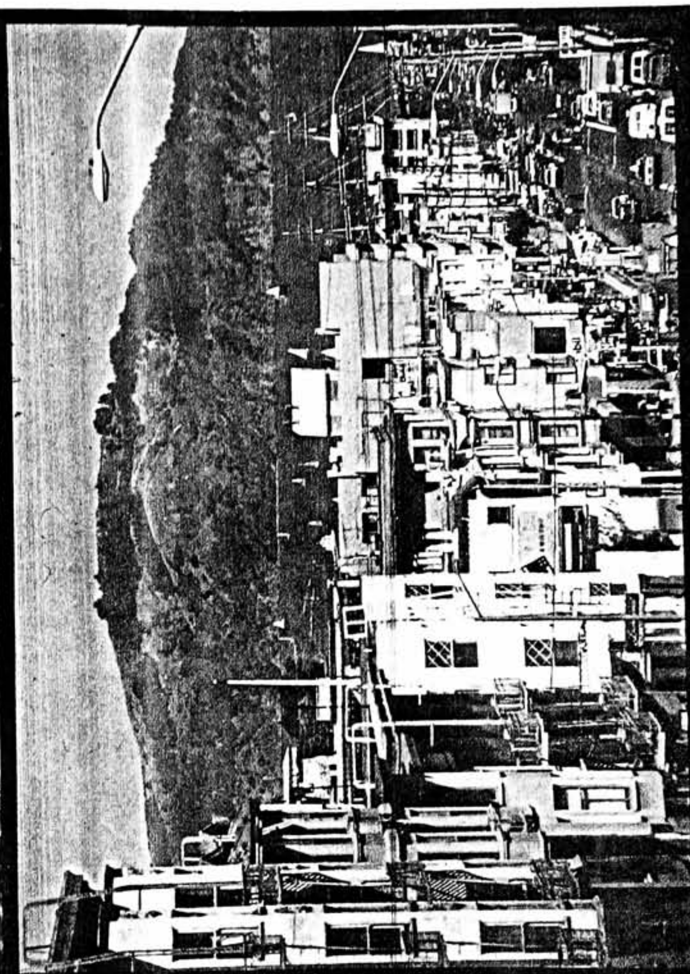
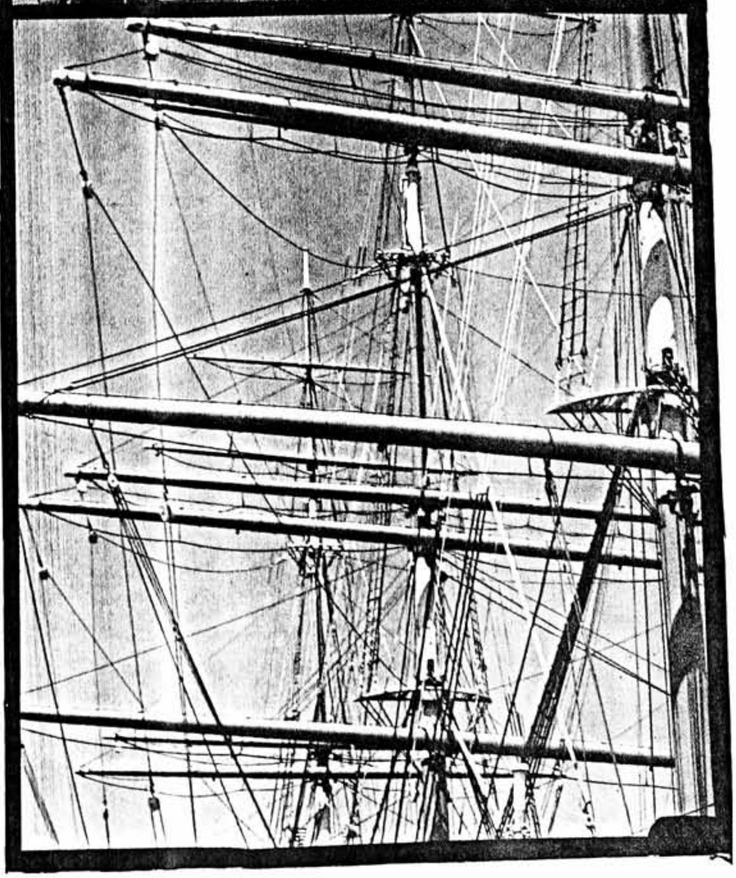
Sample Set No. 3

@Test Samples Screen Frequency :(   )lines/inch

@Group # 1 samples represent :(   )

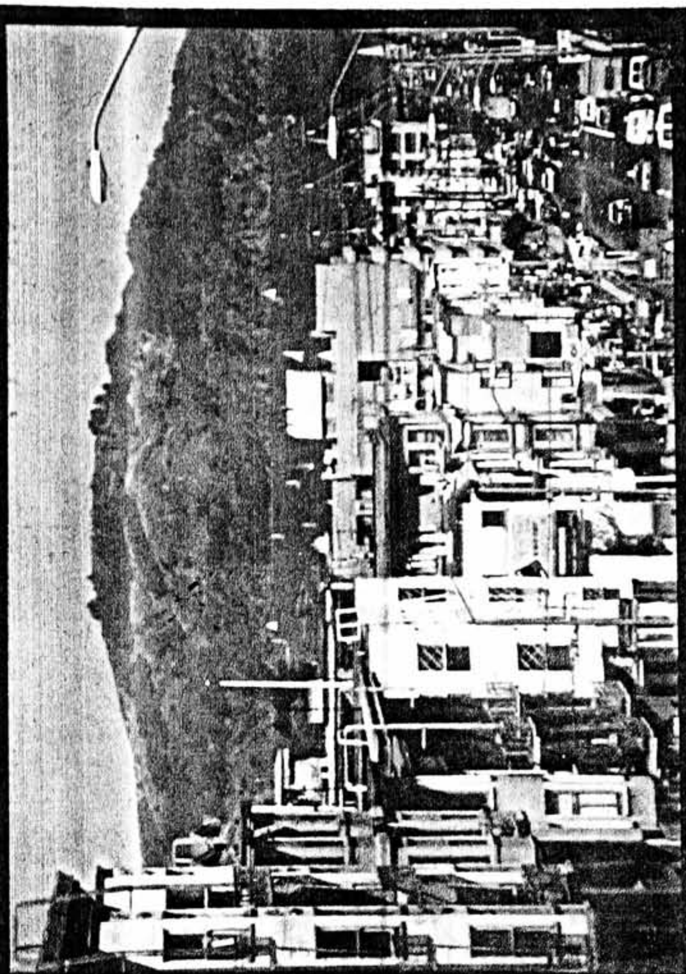
Group # 2 samples represent :(   )

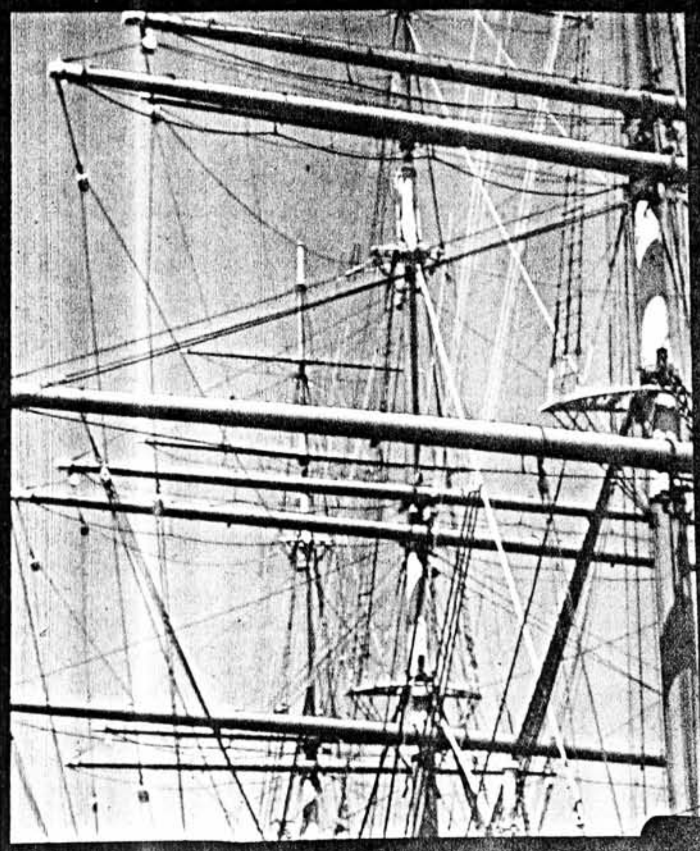




TEST SAMPLE DATA:

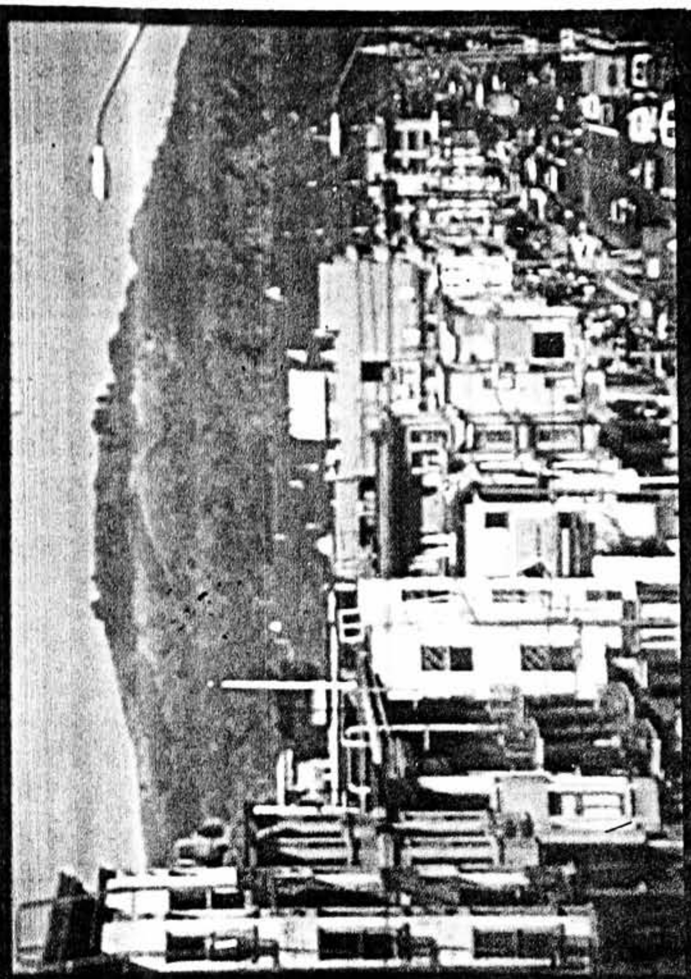
* Original Image Quality:
  SQF = 100
* Reproduction Technique:
  Conventional
* Screen Frequency:
  120 lines/inch

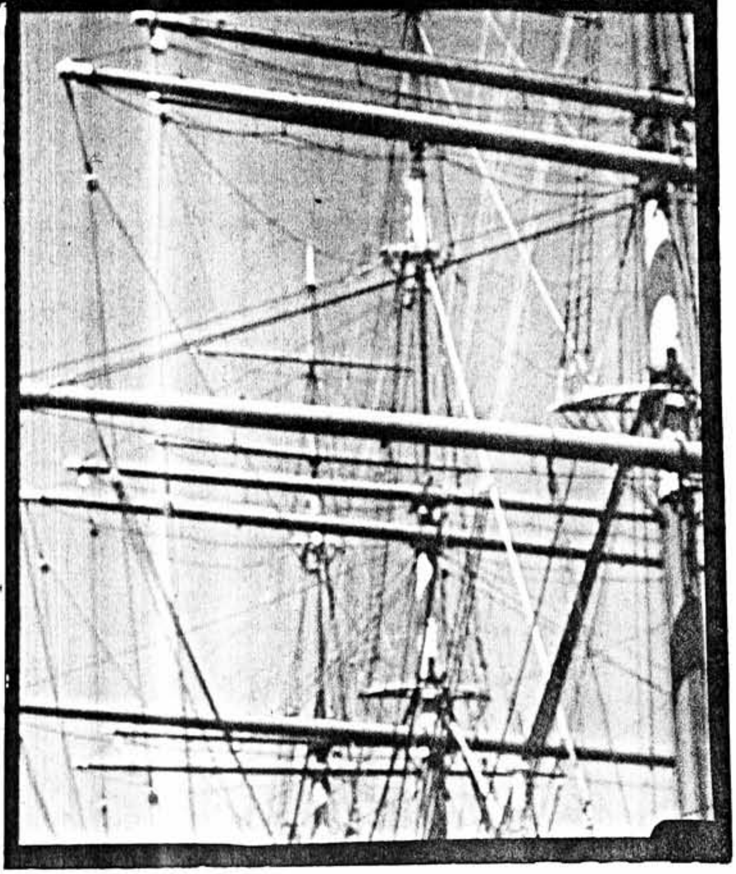




TEST SAMPLE DATA:

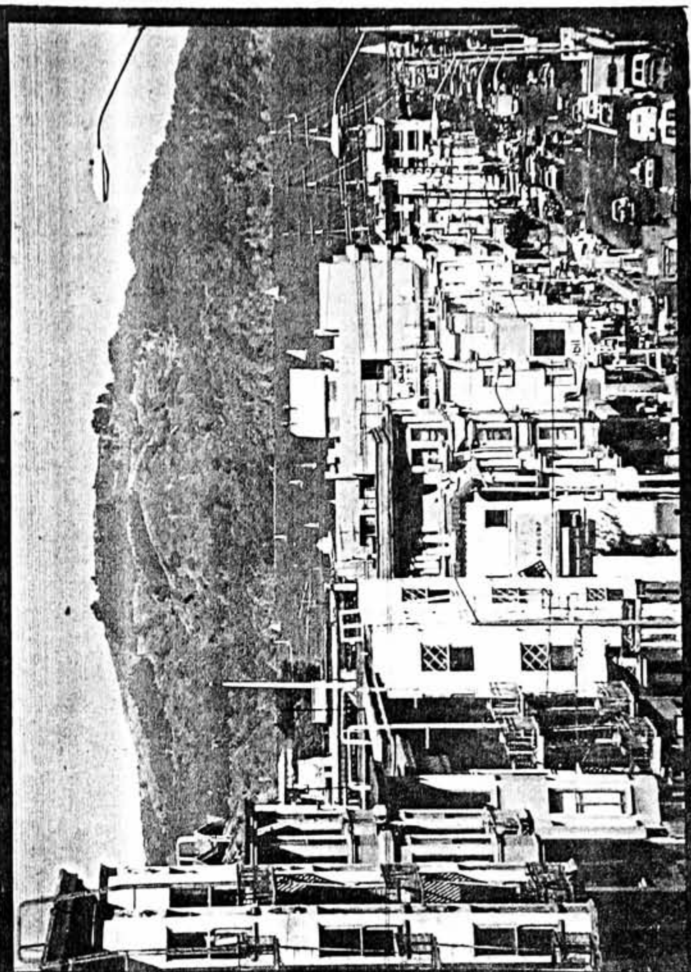
* Original Image Quality:
  SQF = 80
* Reproduction Technique:
  Conventional
* Screen Frequency:
  120 lines/inch

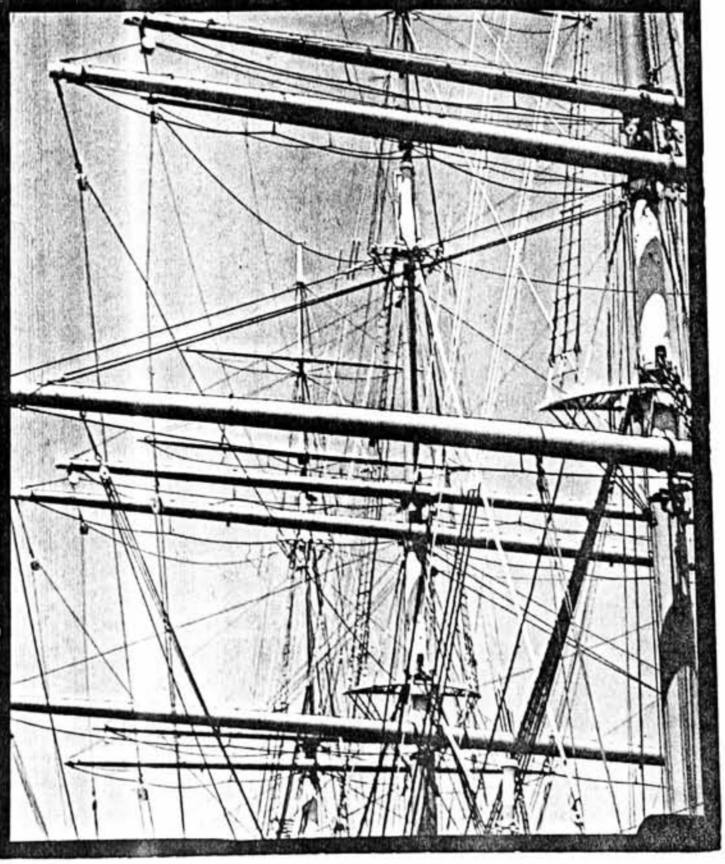




TEST SAMPLE DATA:

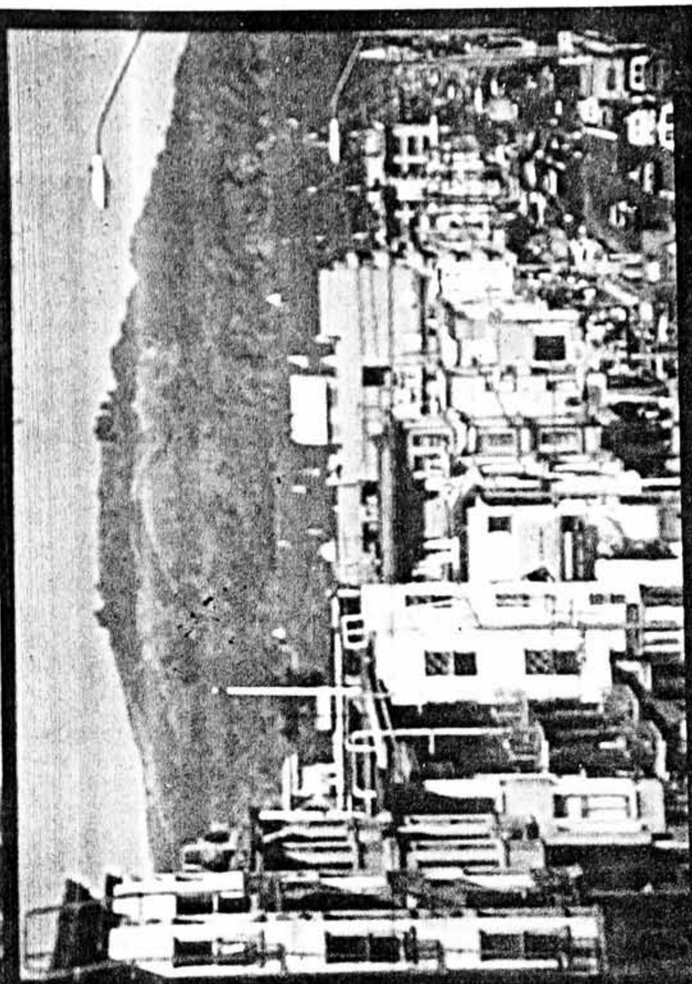
* Original Image Quality:
  SQF = 50
* Reproduction Technique:
  Conventional
* Screen Frequency:
  120 lines/inch

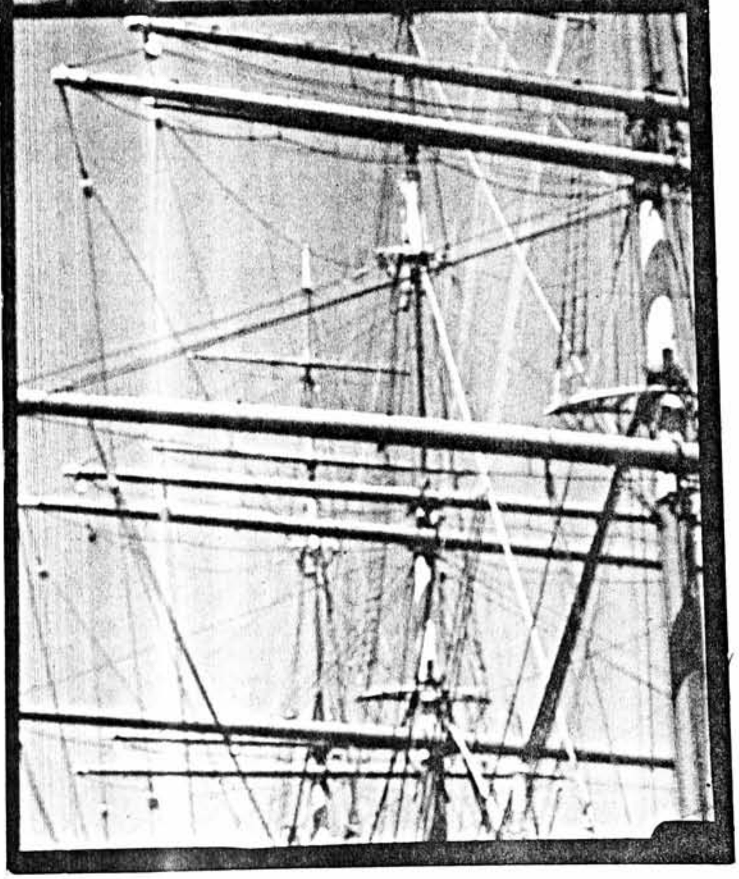




TEST SAMPLE DATA:

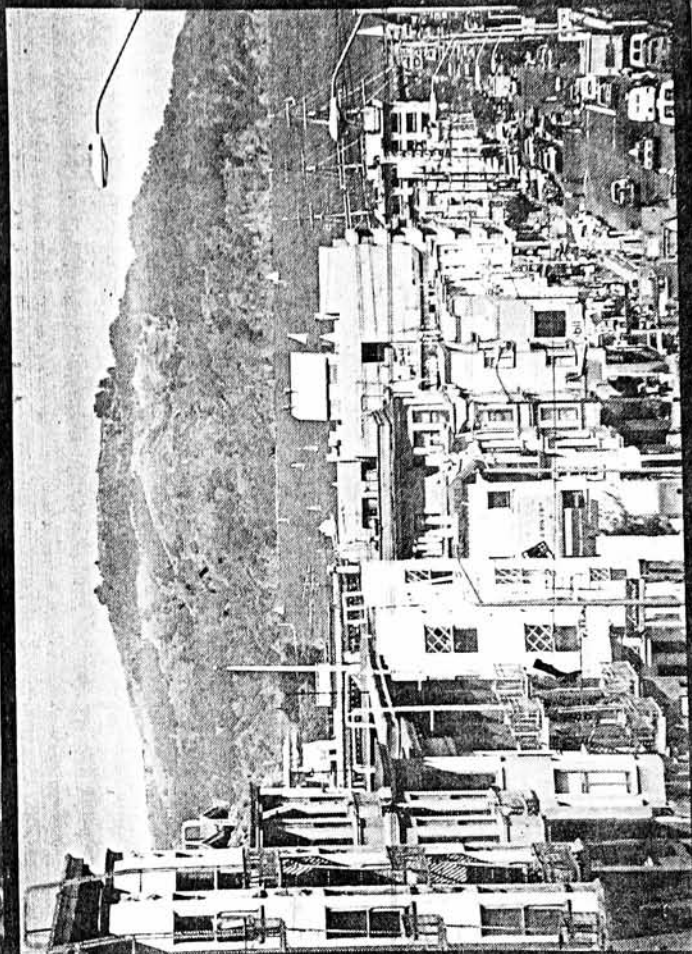
* Original Image Quality:
  SQF = 100
* Reproduction Technique:
  Dot-on-Dot
* Screen Frequency:
  120 lines/inch

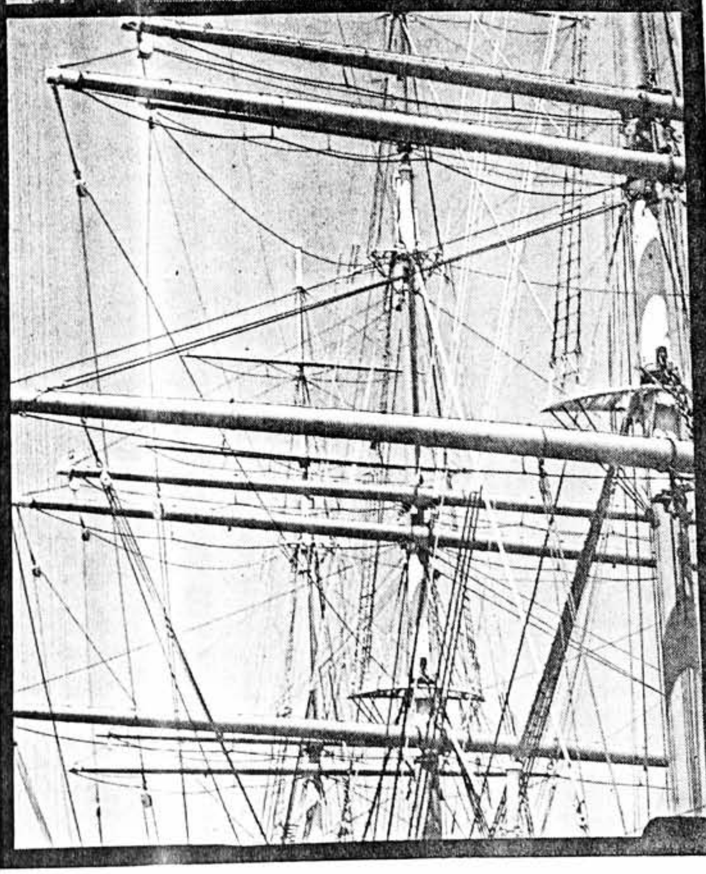




TEST SAMPLE DATA:

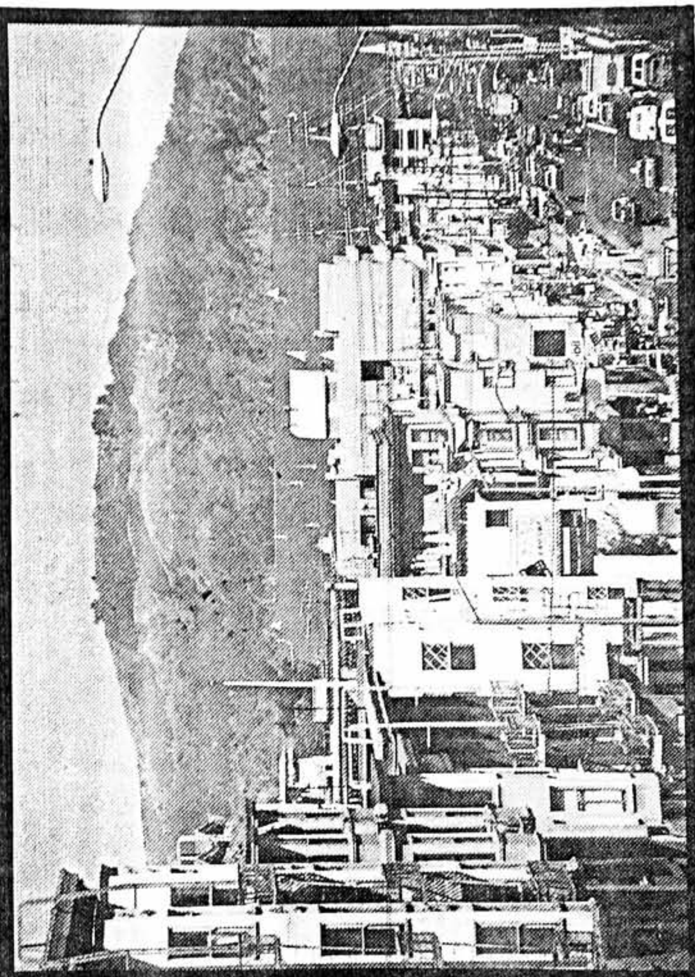
* Original Image Quality:
  SQF = 50
* Reproduction Technique:
  Dot-on-Dot
* Screen Frequency:
  120 lines/inch

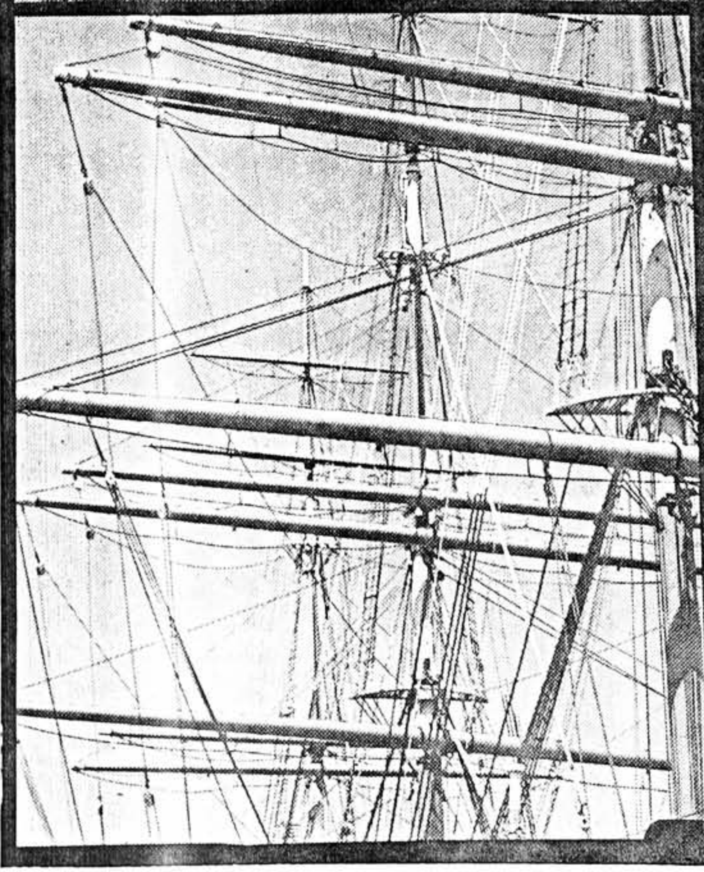




TEST SAMPLE DATA:

* Original Image Quality:
  SQF = 100
* Reproduction Technique:
  Dot-on-Dot
* Screen Frequency:
  85 lines/inch





TEST SAMPLE DATA:

* Original Image Quality:
  SQF = 100
* Reproduction Technique:
  Dot-on-Dot
* Screen Frequency:
  65 lines/inch

VITA

Ted (Te-Chung) Chen received his first Bachelor's degree in Printing Engineer (with a minor in Business Administration) at Chinese Culture University, Taipei, Taiwan from 1972 to 1976. He received his second Bachelor's degree in Printing Management at Western Michigan University, Kalamaoo, Michigan in 1979. After completing his second Bachelor's degree, he worked in the printing industry as a technical management personnel in Milwaukee, Wisconsin from 1980 to 1982.

He attended Rochester Institute of Technology in Rochester, New York from 1982 to 1983 to pursue his first Master of Science degree in Printing Technology. After completing this degree, he worked at the Technical and Education Center for the Graphic Arts Industry, RIT, as a assistant photo technologist. While working in the T&E Center, he entered the Imaging and Photographic Science Department at RIT to pursue his second Master's degree. After completing all coursework at RIT in May 1985, he was employed as a photo process engineer in the semiconductor industry while working to complete his thesis.

His current position is a Q.A. engineer at the mask shop of Digital Equipment Corporation in Hudson, Massachusetts. His work involves the application of photoscience knowledge to fabricate miniture images on a chrome mask for wafer processing.

Born in Taiwan, Republic of China on February 7, 1953.